National Science and Technology Center

Information Synthesis for the Colorado Plateau

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An Analysis of Regional Resource Condition

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National Science & Technology Center

Bureau of Land Management

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EXECUTIVE SUMMARY

Gathering and interpreting scientifically sound information[1] on changing resource conditions to meet increasing demands for limited resources is challenging at any scale. The Bureau of Land Management (BLM) is responsible for the condition and use of resources on more than 240 million acres of diverse Public Lands. A critical agency need is to develop a timely, cost-effective means of assessing resource condition, cumulative impacts, and trends on a regional scale. A properly constructed regional perspective would likely expose resource management needs and reveal previously unrecognized opportunities for cooperation and multiple use alternatives.

In FY`02, the BLM directorate for Renewable Resources and Planning (AD-200) provided the BLM National Science and Technology Center (NSTC) $75,000 to develop and test a strategy for quickly synthesizing, analyzing and interpreting *regional* information on critical resource conditions and trends related to high-priority Public Land management issues. The goal of the first phase of this project was to determine:

- How much information can be gathered in a relatively short period of time for an administratively complex biogeographic analysis area?
- Which information is of most value to Public Land managers?
- What are the reasonable and necessary costs associated with regional information analysis activities[2]?

In February 2002, the Colorado Plateau Managers Group (CPMG) agreed to participate in the project as long as the impact on their time and that of their staff specialists did not exceed two days. A high level of interagency cooperation and a relative abundance of existing scientific information on resource issues made the Colorado Plateau an ideal region for resource assessment strategy development. On March 26, 2002, the CPMG asked the NSTC to synthesize information on:

- the characteristics of the Colorado Plateau's resources;
- significant agents or vectors of change on the Colorado Plateau and the impacts of change;
- risks and opportunities related to resource management on the Plateau;
- information needed to support best management practices; and
- gaps in science-based information important to resource management decision-makers.

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[1] Terms 'information' and 'data' are used synonymously to mean raw, synthesized, and interpreted biological, physical (earth), cultural, and socio-economic data/information in tabular, textual, verbal, and spatial formats of value in the decision-making process. No new data was collected.

[2] Analysis means a process of locating, compiling, synthesizing, & interpreting existing resource information.

In addition to these broad interests, they asked the NSTC to address the issue of "habitat fragmentation and conversion." Their specific fragmentation questions were:

- What is the difference and relationship between habitat fragmentation and conversion?
- How can BLM managers mitigate landscape level fragmentation?

NSTC focused on the CMPG's interests to frame and test a biogeographic regional information synthesis and analysis strategy. NSTC's findings and recommendations for similar endeavors are the subject of this report.

This document is divided into three chapters. Chapter 1 introduces the regional inventory and assessment process and summarizes the pragmatic lessons learned as a result of the Colorado Plateau information synthesis experiment. Chapter 2 contains a summary of Colorado Plateau resource characteristics and answers to the CMPG's specific habitat fragmentation questions. Chapter 3 contains a report on the results of two landscape fragmentation application tests designed to explore potential risks and opportunities for resources management on the Colorado Plateau. Chapter 3 also describes how a USGS "remoteness model" originally designed for the Greater Yellowstone Ecosystem could be used to facilitate land use planning. This report is augmented by nine appendices and five 3"-binders of supporting reference materials (partially annotated), spatial images, and raw data.

Suggested audiences for each portion of the report follow:

Suggested Audience	**Subjects of Potential Interest**	**Location**
BLM WO & field managers	• A discussion about the utility and limitations of regional inventories and assessments. • Strategic considerations for information synthesis: time, most valued information, and cost.	Chapter 1 Appendix D
Colorado Plateau Managers Group	• An inventory and partial resource assessment of the Colorado Plateau. • Fragmentation questions of interest to the CPMG are addressed.	Chapter 2 Appendices A & B Compendium binders
Planners and resource specialists	• A discussion about the utility and limitations of regional inventories and assessments based on a case study. • Strategic considerations for regional information synthesis: time, most valued information, and cost. • GIS was used to analyze landscape fragmentation in general and for a native (game) species.	Chapters 1, 2 & 3 Appendix A, B, & D Compendium binders
GIS technology specialists	• Data layer conversion challenges and solutions. • GIS facilitated analyses and a USGS "remoteness" algorithm expose potential areas of resource management opportunity and concern.	Chapter 3 Compendium binders

Summary of Findings

Chapter 1 introduces the regional resource inventory and assessment process. The amount and type of information that can be gathered in a short time frame depends on the issue of interest. A group of interagency managers and scientists working with private environmental groups interested in the regional perspective will likely generate the largest amount of information and resource management opportunities. Partnerships also leverage resources and expedite assessment of data availability and quality.

The purported "most valuable resource information" ranges from: 1) a simple inventory of regional resources, 2) a graphic presentation of the latest information to address unit specific information needs, 3) an assessment of landscape fragmentation and causes, and 4) an analysis of the condition of mule deer habitat across the region. The distinction between a resource inventory and regional resource assessment is important relative to meeting expectations.

Properly constructed and analyzed regional data can be used to discern the condition of resources within the region, their spatial relationships, potential threats to some resources, and areas of compatible multiple use management opportunities. The results can be used to identify areas of relative sensitivity and value sufficient to justify local action.

Managers can obtain regional resource information to guide management decisions fairly inexpensively. Once regional managers agree to their shared regional data development interests, the cost of synthesizing existing regional data is based on paying for three work elements: 1) project management and report writing, 2) data processing and management, and 3) GIS data conversion and products development. The goals and objectives of the information synthesis ultimately are responsible for framing costs.

Chapter 2 addresses five landscape fragmentation questions posed by the Colorado Plateau managers. The regional dataset demonstrates the influence of roads on the composition and configuration of Colorado Plateau landscapes and habitat. NSTC analyzed baseline composition and configuration of vegetative cover types on the Plateau and created a database of cover types for each Level IV ecoregion, information available in compendium binders. The Plateau contains over 46,000 miles of roads and nearly 16,000 producing oil and gas wells. The Plateau contains a density of roads (0.6 km/km^2) lower than the national average (1.2 km/km^2). Current data indicates that roads have added 174,000 km of high-contrast edge to the Colorado Plateau, changing both the composition and configuration of Plateau plant communities.

Of anthropogenic activities over which managers may exert control, road construction and use can be considered the most significant driver of fragmentation (Saunders 2001; Baker 2000; Forman 2000; Spellerberg 1998;

Forman 1995). Roads are a widespread and dominant feature on the landscapes and the negative impacts of roads are well documented (see Trombulak and Frissell, 2000 and Spellerberg, 1998).

Despite data gaps and a lack of quantifiable information thresholds, BLM managers can begin to address landscape change by continuing to develop their understanding of conditions and drivers that lead to fragmented landscapes, and the commensurate effects on ecological systems. Managers should approach mitigation with an understanding of the degree of fragmentation in surrounding landscapes.

Chapter 3 presents the results of two landscape fragmentation application tests designed to explore potential risks and opportunities for resources management on the Colorado Plateau.

The results indicate that shrub communities are the dominant vegetative cover on the Plateau. Results also suggest changes in both composition and configuration induced by roads. Roads occupy 4.35% of the landscape. When divided by roads, the number of ecoregion and habitat occurrences increased as much as 200,000% - from 1 patch to more than 2,000. Over 2.5% of suitable mule deer habitat is ecologically affected by roads. The ecological effects zone of roads also causes an avoidance behavior in mule deer reducing the amount of available habitat. Fragmentation by roads may therefore affect the size of mule deer home range regardless of habitat quality, particularly in highly fragmented habitats. Year-long habitat demonstrates the highest degree of fragmentation – a condition correlated with larger home range size. Since home range size is inversely related to population density (Loft et al. 1991), habitat fragmentation may create negative pressures on mule deer populations.

These results demonstrate a typical landscape fragmentation pattern: increase in high contrast edge; increase in patch density; division of intact landscapes into small, regularly shaped patches; and reduction in patch area as the road effect zone increases. As road data and vegetative data are updated, managers will be able to track changes in vegetative responses to roads and the distribution, composition and configuration of each ecoregion.

Chapter 3 also describes how a USGS “remoteness model” could be used to facilitate land use planning. This decision support option demonstrates where there are opportunities to preserve important habitat threatened by oil and gas development. The model generates the number of acres that are remote to determine the easiest travel route and travel time to remote areas. For example, only 1% of the Uinta Basin requires greater than four hours to access. Modeling remoteness may be a valuable tool for determining management opportunity. However, the success of this exercise in facilitating land use planning is unproven.

CHAPTER 1: GENERAL FINDINGS AND RECOMMENDATIONS

The Bureau of Land Management (BLM) is responsible for the health, diversity, and productivity of more than 260 million acres of Public Lands, primarily in the western United States. To meet the demands of changing land uses, managers and policy makers must have access to scientifically sound information on the current and changing ecological conditions of Public Lands. This information is critical for sound resource management decision-making and for recognizing and addressing the cumulative effects of land use regionwide.

Gathering and interpreting information on ecological conditions is challenging and time-consuming regardless of the area involved. It is difficult for Public Land managers to devote scarce human resources and time to discovering, acquiring, and synthesizing existing information when so many needs are vying for management's immediate attention. A critical need, therefore, is to develop an efficient and cost-effective method to analyze existing resource information and management activities at multiple scales.

In 2002, BLM managers on the Colorado Plateau expressed strong interest in obtaining regional resource information to guide their management decisions. In response, BLM's National Science and Technology Center (NSTC) staff developed and tested a strategy for obtaining existing information on a subset of regional resources, integrating data from various agencies and sources, evaluating data quality, and converting regional information into a format "useful" to managers. A "useful product" is defined in this context as one that will provide managers with baseline information on resource conditions so that they can efficiently and effectively identify management opportunities. In FY'02, the BLM directorate for Renewable Resources and Planning (AD-200) recognized the importance of such products and provided project funding for a prototype development and testing phase.

> A "useful product" is…one that will provide managers with baseline information on resource conditions so that they can efficiently and effectively identify management opportunities.

Three principles were established in the early stages of this process to guide the development and implementation of an experimental information synthesis strategy:

- Provide information and analysis on variables managers can control (e.g, road development and maintenance).
- Generate no "new" data so that the utility of existing data can be determined.
- Document lessons learned and incorporate those lessons into a recommended resource synthesis strategy applicable to any region.

Staff at NSTC reviewed numerous regional resource assessment and related efforts undertaken by Federal, state and non-governmental organizations (NGOs) such as the US Geologic Survey (USGS), US Forest Service (USFS), US Environmental Protection Agency (EPA), and The Nature Conservancy. Selected outcomes of that review are covered at the end of this chapter. Perceived strengths in prior resource assessment efforts were incorporated into the information synthesis strategy used for the Colorado Plateau and in the general findings and lessons learned discussion which follows.

General Findings and Lessons Learned

The purpose for this discussion is to share NSTC's findings with BLM planners and managers interested in a relatively inexpensive means of quickly assessing and graphically displaying the resources of any biogeographic region.

In practice, many regional syntheses and assessments lack integration, take too long, and have too sweeping a mandate – including ours! Finding and acquiring relevant **regional** resource assessment information in a timely manner, evaluating information quality and utility, and integrating appropriate findings into decision-making is quite overwhelming for many reasons, several of which are summarized here:

1) We "know" that a huge **amount** of information has been compiled but do not know the specifics of what, why, who, where, when, or how the data was collected and processed. Actual data gaps are a mystery.
2) Similar and related information has been collected and processed by multiple entities with overlapping needs. We do not know if these efforts have been **redundant,** resulted in **consistent or inconsistent** findings, or if the information is adequate to address BLM's needs.
3) Available information is constructed or formatted in a manner that renders it **inaccessible** or limits its utility. Data access may also be **restricted** for political, proprietary, or security reasons.
4) We may have **difficulty agreeing** on regional resource assessment objectives and priorities or think there is agreement when there is not. Therefore, the project could get out of hand and the results could be disappointing.
5) We **do not possess the time, fiscal and human resources, or technical skills** required to synthesize regional information. Our immediate concerns are the crises at "home."

Phase I of this information synthesis project was designed to investigate regional resource assessment challenges and test a limited number of strategic solutions.

The Colorado Plateau biogeographic region was selected for a case study, because the region was "known" to be relatively data rich and a regional field managers' working group was in place. The goal of the first phase of this project was to determine:

- <u>How much information</u> can be gathered in a relatively short period of time for an administratively complex biogeographic analysis area?

- Which information is of most value to a subset of Public Land managers?
- What are the reasonable and necessary costs associated with regional resource inventory and assessment activities?

These questions are addressed in the following three subsections.

Regional Information That Can Be Synthesized In 1-2 Months

A prototype regional information synthesis strategy was tested by three people within a self-imposed two-month period (to ensure brevity). Our goal within the two-month time frame was to determine how much relevant data could be synthesized in two months and determine its utility. One month was allocated to locating data sources for regionwide resource status or condition data. Another month was allocated to synthesizing relevant information to create a regional resource inventory of interest to BLM managers on the Colorado Plateau.

Data sources: Federal and state agencies, counties, municipalities, universities and private organizations all had valuable information/data relevant to the Colorado Plateau (see Appendices A and B). Many datasets are the result of joint efforts. NSTC found states and counties to have detailed road data unavailable to Federal agencies. Local offices of Federal agencies may also provide quality data that can be integrated into a regional dataset. Assessment teams should contact local offices for such data. New data become available constantly and a continuous monitoring of available information and updating of source lists is necessary. Despite the efforts of NSTC and EPA Region 8 staff to provide a clearinghouse of regional data, resource managers will be forced to conduct a certain amount of data searches.

Data quality: The quality, volume and variety of information that can be gathered in a short time frame is greatly facilitated by having a clear understanding of how, the inventory data will be used (see "Most Valuable Resource Information" discussion). Because of the partnerships established in this process we were directed to higher quality data than we may have otherwise uncovered.

Inconsistent data quality is presently and will likely remain a persistent obstacle to integrating regional data. Data availability, currency, scale, compatibility and standards vary across jurisdictional boundaries making data synthesis challenging and prone to bias. High quality data may often be reduced to its coarsest form in order to integrate it (make it consistent) with data of lesser quality.

Time and core resources required: It takes a small team (with at least one member well versed in GIS) devoted to the data sourcing, collection, access, and the synthesis process to meet basic regional resource information inventory goals within 2 months. NSTC was able to review region-specific scientific literature, web resources, and datasets in one month and prepare resource inventory lists and tables (see Appendices A and B) in the second month. The data conversion and integration process (critical for analyses) using a GIS was technically challenging and could only have been accomplished through a GIS expert. It took him more than three months to complete this process and produce appropriate products.

Partnerships are essential: NSTC took advantage of several federal partners (particularly the USGS and EPA) to facilitate: rapid identification of data sources, data access, discovery of data characteristics, data conversion, metadata validation, and data quality and utility assessment. Several non-land management agencies partnered with the NSTC because they want to see results (analyses) from regional data they have compiled or generated.

Finding potential partners or collaborators can take substantial time. We were quite fortunate that an active network of federal partners had already compiled so much information on the Colorado Plateau. We recommend that such a consortium be sought out early wherever a regional resource inventory or assessment is contemplated.

A group of interagency and intergovernmental resource managers and scientists, academics, and environmentally focused private organizations interested in the regional perspective will probably generate the largest amount of information and realistic regional resource management opportunities. If this is not the situation, the data source identification, collection, integration, and analysis processing time could be extensive.

Most Valuable Resource Information

A primary objective of Phase I of this information synthesis project was to discover the resource information of most value to a group of BLM field managers and some effective ways to use and present that information. NSTC learned upon briefing the CMPG on October 18, 2002 that in spite of significant preplanning with the CMPG, a major difference in needs and expectations from this type of project remains. While the majority of those needs were met, we learned that demonstrating that needs were met requires special effort and forethought.

The purported “most valuable resource information” ranged from: a) a simple inventory of regional resources provided in tabular format, b) a graphic presentation of the latest information in certain locales to address unit specific information needs, c) a current representation of landscape fragmentation and causes, and d) an analysis of the condition of mule deer habitat across the region. All of these interests are valid, but the regional information synthesis effort required to meet each need is quite different.

To determine the most valuable resource information for a group of regional managers and planners, NSTC surmises that all parties involved should (1) fully understand the differences between resource inventory and assessment data and (2) the regional managers group must predetermine and agree to a set of questions that can be appropriately addressed through a regional resource assessment. To facilitate this understanding, we suggest that the following two questions be carefully considered.

What is the difference between a resource inventory and assessment?

A **resource inventory** is a simple accounting for what occupies a predetermined area at some fixed point of time.

A **resource inventory** is a simple accounting for what occupies a predetermined area at some fixed point of time. Inventory data may include information on the condition and distribution of each resource inventoried. A **resource assessment** on the other hand, implies that an analysis of the condition, threats to, and distribution of one or more resources is involved. A simple way to think of the difference is that an inventory is a series of lists or tables and an assessment makes relative sense out of or defines relationships between items on those lists/tables. The process of **information synthesis** is required for both a resource inventory and resource assessment.

This distinction turned out to be of importance relative to meeting expectations as some of the project customers expected the NSTC to simply improve the region's preexisting resource inventory data by compiling it, while others were looking forward to how these data could be used to address management issues.

A regional **resource assessment** should analyze the condition of, threats to, and distribution of resources of management interest.

Is synthesized regional data likely to meet __my__ needs?

At our final pre-work meeting with the CMPG in March 2002, the common management issue of interest appeared to be "habitat fragmentation" and its potential impact on regional mule deer populations. NSTC construed this to mean that indicators of habitat fragmentation would constitute the regional resource inventory data of interest. Those expecting a compilation of existing inventory data would have a subset of their needs met (see Appendix C) and those interested in the potential applications of those data would have their needs met as well.

By choosing a management issue, the CMPG limited the resource inventory data search and enabled data acquisition and processing within two months. The management issue selected by the CMPG, however, was both immensely challenging and comprehensive as landscape fragmentation can be reasonably viewed as a surrogate for and indicator of landscape integrity and health (see Chapter 3 for a full justification and citations). This management issue, in retrospect, is so huge that it deserves far more attention than the NSTC could facilitate in a few months. What we were able to do was provide a solid starting point for further work.

The issue focused regional assessment performed would probably have been of more immediate value if the expressed management need not been so wide open. NSTC recommends that regional managers and planners understand the following to maximize the potential for immediate applicability of resource assessment results: (1) the regional information users must have a strong and equally shared vision of regional information needs (unanswered questions) which are documented; and (2) as end users, regional managers must have a basic understanding of the inputs, potential value, and limitations of regional datasets, particularly resource assessments.

Mixed Management vision: Insufficient time, people, and money make it extremely difficult for any manager to see the "forest for the trees." In addition, land administrators have no control over their neighbors and never will. Understanding and resolving local resource management conflicts is a daunting enough task; imagine participating in regional problem solving when no agreement has been reached on what the problem is or what questions need to be answered to solve the problem.

In the Colorado Plateau case study, NSTC staff and the CPMG appeared to come to an understanding on the desired resource assessment outcomes of the Colorado Plateau information synthesis project. Habitat fragmentation was the agreed upon management issue and three related questions were posed. Based on the reactions of the CPMG to the limited results presented to the managers, NSTC feels that two things might have happened and both are important to consider when choosing to develop regional data for management use. First, the NSTC probably did not present all of our findings in such a way as to satisfy the full range of interests. NSTC hopes to remedy this through this report and a second presentation. Second, the CPMG seems to have a mixed vision of the regional approach to resource management as was made evident by their reaction to the Colorado Plateau mule deer habitat information provided to them.

To address CPMG interest in a decline in the regional mule deer population, NSTC synthesized and graphically displayed winter, summer, and year-round mule deer habitat for the Colorado Plateau. A "so what" kind of response was perceived and expected. NSTC had prepared for this by focusing on the northern portion of the Colorado Plateau where mule deer habitat of all types is being impacted by development. NSTC staff graphically demonstrated where each type of mule deer habitat was most threatened by landscape fragmentation and areas that were least disturbed. NSTC also presented a decision support option using a "remoteness model" to demonstrate where there were opportunities to preserve important habitat threatened by oil and gas development. While this demonstration of potential applications of regional resource assessment data greatly interested the land managers in the area studied, it was clearly not of interest to others. We are not sure if this mixed reaction was due to our failure to articulate the purpose of the demonstration, or if there is a lack of common management interest in declining mule deer populations on the Colorado Plateau.

What regional assessment data *can* do: Properly constructed and analyzed regional data can be used to discern the condition of resources within the region, their spatial relationships (e.g., density, distribution, and significance), some potential threats to some resources (e.g., oil & gas development impacts on mule deer habitat), and areas of compatible multiple use management opportunities. The results can be used to identify areas of relative sensitivity and value sufficient to justify local (district level) action.

Conducting a resource assessment of the Colorado Plateau enabled NSTC to identify areas of management concern by synthesizing a regional dataset of land cover, roads, land use and habitat at a scale useful to managers. Some managers, however, thought that current local data was of more value to them than a complete regional dataset. This perspective does not, of course, reflect a regional interest. Nevertheless, it may be beneficial to have even inconsistent data available. If this were to occur, managers need to understand that defensible relationships can not be determined by compiling the 'best" data for all locales.

What regional assessment data *cannot* do: The most valuable information is that which best addresses the management issue of interest at the "right" scale. To be "right", the regional data must be consistent. For example, NSTC had access to digital USGS 1:24,000 scale maps, but choose to represent road density and locations using digital USGS 1:100,000 scale maps due to a huge disparity in the age (data accuracy) of 1:24,000 maps. This choice allowed us to interpret relative road density information accurately and draw meaningful conclusions from a regional perspective. Had we used maps of different ages at the 1:24,000 scale or finer, no regional relationships could be inferred. An attempt to analyze these inconsistent data in a regional context would misrepresent relative conditions.

The fact that we had to use USGS 1:100,000 (course) scale maps demonstrates the difficulty in working with regional data sets and the limits of the application of those data. Data utility and accuracy may be reduced when integrated to a regional dataset. Because scientific uncertainty is magnified by scale, regional resource assessment data is best used to profile broad-scale conditions and areas needing finer scale analysis.

Regional data can be made useful even when it is imperfect: NSTC found few regional datasets that represent real time conditions or complete snapshots of conditions at any time. Complete, real time human population conditions in the US, for example, would be represented by the census data for the year it was collected. That means we have access to complete, real time population data every 10 years. These data allow us to accurately show human population demographics, distribution, and growth associated trends in every region in the US. Very few regional data sets of such depth and quality are available.

A major disappointment, but important finding was that few data (excluding the US Census data) for the Colorado Plateau had been replicated across the Plateau at two or more points in time. Aerial photography is the one exception we could find, but since the information was not digitized, NSTC could not use it to analyze land use and vegetation trends regionwide--a prime requisite for characterizing landscape fragmentation and conversion in modern times. Of course, "someone" could synthesize and digitize the replicates of aerial photography across the Plateau. The BLM does not have the funding to make this happen, but could influence USGS priorities.

There are ways to deal with some dated and incomplete regional data. For the Colorado Plateau case study NSTC created a 1:24,000 topographic map age index of the region (Figure 4) which is new data for the larger Colorado Plateau resource inventory.

To compensate for out-of-date and incomplete roads data on the Colorado Plateau, NSTC contracted with the USGS to map all visible roads on four contiguous 1:24,000 orthophotos adjacent to Vernal, Utah. Sixty percent more roads were found in this sample comparison between othrophotos and existing road data. Additional sampling of a spectrum of landscapes on the Colorado Plateau would allow the BLM to develop correction factors to infer road density real time throughout the Colorado Plateau. The USGS Mapping Division has offered its services for this purpose.

Reasonable and Necessary Costs

To provide a baseline for estimating reasonable and necessary costs, NSTC offers the following observations assuming that only existing information is to be accessed. Managers can obtain regional resource information to guide management decisions fairly inexpensively. Once regional managers agree to their shared regional data development interests (costs associated with this activity are unique to each region), the cost of synthesizing existing regional data is based on paying for three work elements:

1) Project management and report writing (6 months)
2) Data processing and management (3 months). Partnerships and collaborations speed up data sourcing and increased access to data and the efficiency of data integration.
3) GIS data conversion and products development (4 months). This time can be reduced by approximately one month if a technician or specialist is familiar with the software program used to analyze the dataset.

Additional subject matter expertise will be needed at times to identify resource inventory data needs and for resource assessment analyses. Work required to develop correction factors to mitigate out-of-date and or incomplete data should be considered and treated as new data collection. New data collection substantially increases costs, but commensurate benefits could more than justify the added cost. The goals and objectives of the information synthesis ultimately are responsible for framing costs. A simple compilation of common, readily accessible resource data could by accomplished in two months by one excellent data sleuth. A complete resource inventory could take years depending on the type of information required. A resource assessment follows the same logic except that substantially more time may be required for analyses, report writing, and presentation to regional managers.

In conclusion, reasonable and necessary costs are dependent on desired outcomes.

Bioregional Information Synthesis - Strategic Considerations

Staff at NSTC reviewed many information synthesis (including resource assessment) strategies developed to improve understanding about a region so that one or more problems could be resolved. Reference materials in the compendium Volume 1 “Bioregional Assessments” provide an abundance of ideas and examples of information synthesis strategies at the regional scale.

Generally, regional assessments integrate a broad range of information about the social, economic, and ecological conditions within a region in order to provide a basis for making decisions and taking action (Graham and Jain 1999; Johnson et al. 1999). A *bioregional* assessment integrates similar information on an ecosystem-basis. The region is delineated by natural processes and elements rather than by planning units and political jurisdiction (Johnson et al. 1999; Bailey 1988).

Few established criteria exist to insure successful implementation of the information synthesis process. The rationales and methodology for conducting syntheses often vary. However, a review of the literature and current regional assessment techniques reveals three essential components: a) clear goals for the synthesis effort; b) a framework for data collection, processing, interpretation and analysis; and c) a plan to measure success.

Goals for a Regional Information Synthesis Effort

The primary goal of a regional information synthesis effort is usually applications oriented and the end user is usually a natural resource management decision-maker. The NSTC literature review found four common goals for regional resource assessments:

- Integrate disciplines, synthesize ideas and convert synthesized information into a form useful to managers.

When planning a regional resource information synthesis strategy, it is important to include regional partners and an adequate array of technical specialists (Greis and Wear 2002; Mysz et al. 2000; Taylor et al. 2000; Graham and Jain 1999; Michener 1999; Dahms et al. 1997; Thornton et al. 1994; and others).

- Support decision making with a broad-scale perspective of resource conditions.

If the effort is issue based, the information synthesis strategy should be designed to include the whole ecosystem likely to be affected by common change vectors so that cause and effect relationships may be fully comprehended (Shinnenman et al. 2000; Busch 1999; Graham and Jain 1999; Hirvonen 1999; Michener 1999; Dahms et al. 1997; Anderson and Dziegielewski 1996; Thornton et al. 1994; Helmick 1993). An ecosystem, or ecoregion, approach will facilitate a broad landscape perspective.

- Provide guidance and recommendations to managers about how to improve and maintain ecological integrity with a clear, concise, and accessible snapshot of conditions;

An effective information synthesis strategy should provide decision makers with science-based management alternatives by placing policy questions into a conceptual framework for analysis (Swanson and Greene 2000; Hirvonen, 1999). The synthesis strategy should include provisions to assess the cumulative impacts of management actions (Greis and Wear 2002; Diaz et al. 2001; Swanson and Greene 2000; Busch 1999; Franklin et al. 1999; Graham and Jain 1999; Hirvonen 1999; Michener 1999; Dahms et al. 1997; Thornton et al. 1994; Ballard et al. 1983). A regional information synthesis cannot, and should not be used to address very technical or localized issues.

- Generate further questions and offer a way of quantifying choices so that consequences are better understood.

The questions for analysis should be defined by establishing clear criteria and indicators (Busch 1999; Diaz et al. 2001; Franklin et al. 1999; Graham and Jain 1999; Hirvonen 1999; Michener 1999; Burkhart and Buhler 1997; Dahms et al. 1997; Thornton et al. 1994). Uncertainty should be defined by its causes, degrees, risks and consequences. Assumptions, uncertainty, and data limitations should be stated outright.

In conclusion, resource managers engaging in a regional information synthesis effort must establish a clear understanding of the goals of the project (desired outcomes). They also should carefully consider the scientific basis of the data collected, the ecoregional context, and the inherent limitations of regional resource assessment data.

Strategic Framework

NSTC's extensive review of pertinent literature and personal interviews with those who had led or participated in information synthesis efforts gave us a practical understanding of the state-of-knowledge regarding information synthesis strategies.

The strategy chosen for the Colorado Plateau information synthesis prototype is based on work by Johnson et al. (1999). Johnson and his colleagues conducted an extensive examination of seven regional resource assessments. They identify four components vital to a regional assessment: (1) defining a bioregional context, (2) conducting the assessment, (3) interpreting results and outcomes, and (4) building the capacity for understanding. Based on the Colorado Plateau case study and lessons learned, we recommend the following four step information synthesis strategy:

Step one: Interested managers identify a regional issue of shared concern. With subject matter assistance, they:
- clearly and concisely articulate the problem;
- decide which questions, if answered, will contribute substantially to resolving a regional problem; and
- agree on the regional resource assessment goal and objectives.

Step two: Subject-matter experts identify required data and the appropriate geospatial scale to characterize these data. They:
- establish data requirements criterion: consider social, economic, and biological information;
- delineate assessment boundaries based on the management issue, agency need, biogeophysical and socio-economic attributes of the area;
- determine temporal/ spatial domain and scale of analysis; and
- Identify and investigate potential data sources.

Step three: Responsible staff collect and process relevant data. The project lead:
- establishes processing standard operating procedures;
- collates and, as appropriate using subject-matter experts, analyzes data;
- document findings in a spatial context and in a written report.

Step four: The project lead is responsible for determining if the goals and objectives of the resource information synthesis were met. S/he:
- obtains managers' feedback;
- monitor's product use; and
- reports findings.

Guidance on how to implement this strategy is provided in Appendix D.

This information synthesis strategy should be applicable to any biogeographic region interested in either a resource inventory or resource assessment assuming the following conditions are met:

- The region's managers are interested in regional information, understand its limitations and value, and are willing and able to participate;
- Resource specialists capable of managing bioregional information, and adequate funding are available to complete the anticipated work; and
- Expertise and equipment are available to support information synthesis needs.

Note: the broad applicability assumption has not been tested.

Although this strategy is designed to be accomplished in its entirety in 6 months, significant effort is required to complete each of the strategy's four steps. If sufficient resources cannot be committed to the effort during the six months, the process will take more time. For example, if the region's managers cannot convene a successful face-to-face meeting at the onset, the information synthesis and analysis work cannot begin. Management's input is essential for steps one and four and advised for steps two and three.

Plan to Measure Success

The absolute value of the information synthesis is an open question. As noted in "General Findings and Lessons Learned" at the beginning of this chapter, Colorado Plateau managers had mixed reactions for uncertain reasons. Further customization of the analysis may be necessary to determine the absolute value of the information synthesis strategy recommended in this report.

Three metrics (questions) posed by Johnson et al. (1999) are considered here to assess the preliminary success of the NSTC strategy:

- *Was the synthesis focused – did the assessment lead to solution of the problem that caused it to take place?*

As indicated previously, issue identification is critical to project success. However, too much time spent defining the issue can be a barrier to synthesizing regional information. The regional manager's work group could become discouraged and disengage.

In the Colorado Plateau case study, NSTC tested a strategy that facilitated rapid issue identification and specific-issue focused questions. The synthesis strategy remained focused on assessing the fragmentation of Colorado Plateau landscapes, though the synthesis does not prescribe management action to mitigate fragmentation. Again, customer satisfaction with the work accomplished is uncertain. Because of this, NSTC recommends giving more attention to educating managers on the value and limitations of regional resource assessment before they select project goals and objectives. A regional management issues selection and use decision support tool with appropriate criteria imbedded should be developed and tested.

- *Was the synthesis contextual – did the assessment lead to solutions of the problem that caused it to take place?*

Ecoregions are well suited to regional analysis, but little regional data is available in that format. While the Bureau is transitioning to the use of hydrologic units for identifying priority management areas, such a framework is not always appropriate for analyzing fragmentation. Ecoregion boundaries are best suited to providing context for broad-scale analysis of terrestrial ecosystems. We observed that a deficit in regional data can be mitigated by engaging in coordinated partnerships that make data broadly available to all interested participants.

Addressing regional issues requires partnerships with government agencies, and public and private institutions. The collaboration in this project exemplifies the potential for a long-term partnership between USGS and BLM, reflecting scientific research paired with practical land management. A regional information synthesis represents a starting point for scientists and resource specialists to work with land use planners to develop thresholds for resource condition that can be applied to specific management prescriptions. A regional information synthesis may also present opportunities to merge goals and objectives with other regional resource management efforts.

- *Was the synthesis integrated – were the results considered in management analysis and actions?*

Integration of synthesized and analyzed regional resources data in management decisions has yet to occur, but a resource conditions baseline has been created to monitor and evaluate the impact of roads on natural resources regionwide. The process of information synthesis is iterative. Once baseline conditions are established, and as appreciation for the value of regional data grows, managers may be more inclined to integrate regional data in management decisions.

In conclusion, NSTC employed a strategy of regional information synthesis to identify a regional management concern and gather data on land cover, roads, land use and habitat at a scale useful to field managers. The dataset portrays the influence of roads on the composition and configuration of the Colorado Plateau landscape and habitat. The information and maps NSTC generated through this process provide baseline information on the condition and characteristics of some Colorado Plateau resources at a specific time. The resource assessment results (see Chapters 2 and 3 and associated appendices) should be of value for predicting cumulative impacts associated with landscape fragmentation. New and very interesting information building blocks have been added to the regional managers' resource management tool kit. If requested, NSTC will be happy to facilitate the use of these results.

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CHAPTER 2: COLORADO PLATEAU INFORMATION SYNTHESIS

In this chapter we discuss how well the NSTC regional information synthesis process met the needs of Colorado Plateau resource managers expressed in a March 2002 meeting. A project objective was to provide managers with regional information on ecological conditions to aid them in identifying potential resource management opportunities. NSTC staff used the Colorado Plateau as a study area because land managers on the Plateau had previously expressed a need for a synthesis of available regional information. That need is addressed in the following sections. The high level of interagency cooperation and existing scientific information made the Colorado Plateau an ideal region for testing the information synthesis strategy discussed in the previous chapter.

This section addresses five principal questions regarding the data needs of the Colorado Plateau managers: 1) what are the characteristics of the Colorado Plateau's resources, 2) what are the significant agents or vectors of change on the Colorado Plateau, 3) what risks and opportunities does the information reveal, 4) what information is needed to support best management practices, and 5) what information gaps are important to resource management decision-making? Detailed discussion addressing these information needs can be found in the following sections and in Chapter 3.

Characteristics of the Colorado Plateau's Resources

NSTC conducted a preliminary assessment of the representative vegetative types and ecosystems across the landscape. To do so, we synthesized information on soil types, elevation, precipitation, vegetation and ecoregional classifications (available on CD through NSTC). Historical and science-based information has been previously developed to describe the Colorado Plateau (see http://www.cpluhna.nau.edu/). NSTC has expanded this information by developing a regional data base of vegetative cover, roads, land use and mule deer habitat on the Colorado Plateau.

In the course of this information synthesis process NSTC developed several geospatial data layers, regional datasets and regional maps depicting the characteristics and condition of resources across the Colorado Plateau. The Plateau was divided into 100 individual ecoregions. We analyzed baseline composition of vegetative cover types on the Plateau and created a database of cover type profiles for each of the 100 ecoregion (data available in compendium binders). These profiles provide insight into the way cover types are distributed across the landscape and how they are related to land uses such as roads.

The resource inventory data complied for the region include:

- elevation;
- soil type;
- ecoregions;
- acres of vegetation by type;
- history of fire occurrence;
- acres of mule deer habitat;
- total road coverage;
- road densities;
- oil and gas well sites;
- well densities; and
- jurisdiction and land ownership.

Before synthesizing available information on the resource characteristics of the Colorado Plateau, we defined the boundary of our landscape using Colorado Plateaus Level III ecoregion boundary[3] (Omernik, 1995). Omernik's level III ecoregions include 84 regions that cross jurisdictional and administrative boundaries throughout the US (Figure 1). The regions are generally similar in the type, quality, and quantity of environmental resources (Omernik 1995). Ecoregions are differentiated through analysis of spatial patterns that reflect the differences in geology, physiography, vegetation, climate, soils, land use, wildlife, and hydrology (Woods et al. 2001; Host et al. 1996; Omernik, 1995; Bailey 1988). Ecoregions are areas that may be defined hierarchically at a range of scales to serve as a spatial framework for broad research, assessment, monitoring and management of ecosystems (Woods et al. 2001).

The Colorado Plateau is divided into 100 Level IV ecoregions comprising 8 classes (Figure 2). NSTC analyzed baseline composition and configuration of vegetative cover types on the Plateau and created a database of cover types for each Level IV ecoregion (available in compendium binders). Descriptions of each ecoregion can be found in Appendix H and an example profile is provided in Figure 3. We sought to provide a baseline description of the Plateau by quantifying landscape composition and configuration of each ecoregion both with and without roads. We lacked a "pre-roads" vegetative dataset for the Plateau making it difficult to assess changes in composition and configuration of cover types. However, as road data and vegetative data are updated, managers will be able to track changes in vegetative responses to roads, and the distribution, composition and configuration of each ecoregion.

The analysis of these data confirms what is commonly known – shrub communities are the dominant vegetative cover on the Plateau. The dataset also demonstrates the influence of roads on the composition and configuration of Colorado Plateau landscapes and habitat. The Plateau contains over 46,000 miles of roads and nearly 16,000 producing oil and gas wells. Detailed densities and location information is available in a compendium binder to this report.

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[3] Included within the Level III Colorado Plateaus boundary are a number of Level III Rocky Mountain ecoregions. The Rocky Mountain ecoregions (including the Abajo, Henry, Navajo and La Sal Mountains) were omitted from this analysis because they represent distinctly different ecological zones that warrant separate analysis.

Current data indicates that roads have added 174,000 km of high-contrast edge to the Colorado Plateau. Road impacts usually extend beyond the physical limits of the road. The limits of ecological effects are described as the road effect zone (Forman 1995; Forman, 2000) or the depth of edge influence (Reed et al. 1996). The road-effect zone may be many times wider than the road and in some cases, may extend up to 300 meters from the edge (Forman and Deblinger, 2000). In this regard, roads comprise a larger portion of the landscape than that consumed by the physical road – an important point when analyzing landscape fragmentation.

Figure 1. Level III Ecoregions of the continental United States (Omernik 1995)

Although current literature focuses on forest fragmentation, where fragmentation effects may be more obvious and land uses more easily documented, landscapes dominated by shrublands may experience edge effects far beyond 60m (Rost and Bailey, 1979). Edwards et al. (1998) differentiated ecoregions by roads, where 'road' was defined as a 1-km-wide corridor from the center of the road. Larsen and Parks (1997) found an 85m buffer on both sides of road might help prevent landslides from blocking roads. Angold (1997) reported 200m effect zones for large roads and a positive correlation between effects and road width. Reed et al. (1996) defined depth of edge at 50 and 100m.

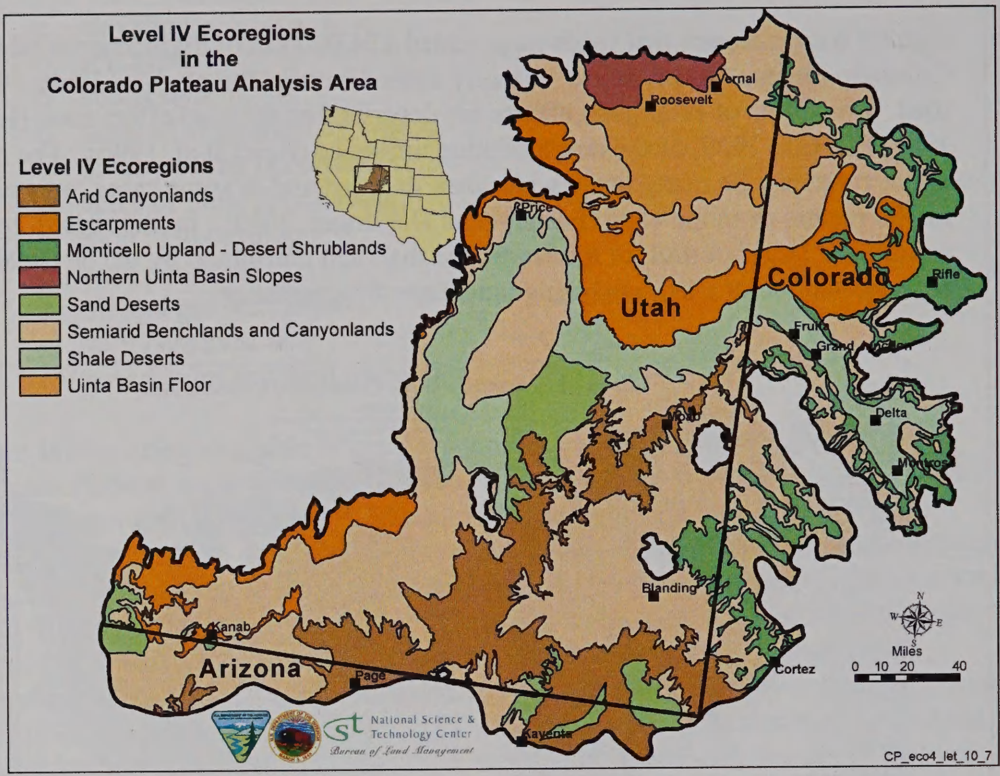

Figure 2. Level IV Ecoregions of the Colorado Plateau (Omernik 1995)

We were faced with choosing a data resolution that captured physical roads as well as an average road-effect zone. After reviewing the literature on the impacts of roads and edge effects, we chose 60m resolution to quantify the road effects zone.

The 174,000 km of road-induced edge divides the Plateau into numerous small, regularly shaped, evenly spaced landscape fragments. The synthesis and analysis of data suggests fragmentation by roads may affect the size of mule deer home range regardless of habitat quality, particularly in highly fragmented habitats. Data on the level of use for each road type is needed to make more accurate estimates of road effects on the landscape and mule deer habitat. The analysis of landscape composition and configuration for each ecoregion indicates the Uinta Basin-Floor has experienced a high degree of fragmentation. The Basin has a relatively low density of vegetative edge, but a high road density and high degree of edge contrast compared to other ecoregions. Fragmentation of year-long habitat in the Basin may therefore place negative pressures on mule deer populations. A USGS-based remoteness model was used to show areas within the Basin most isolated from roads and least impacted by road-induced fragmentation. Further analysis of these areas, vegetative cover, and habitat condition may reveal mule deer habitat management opportunities.

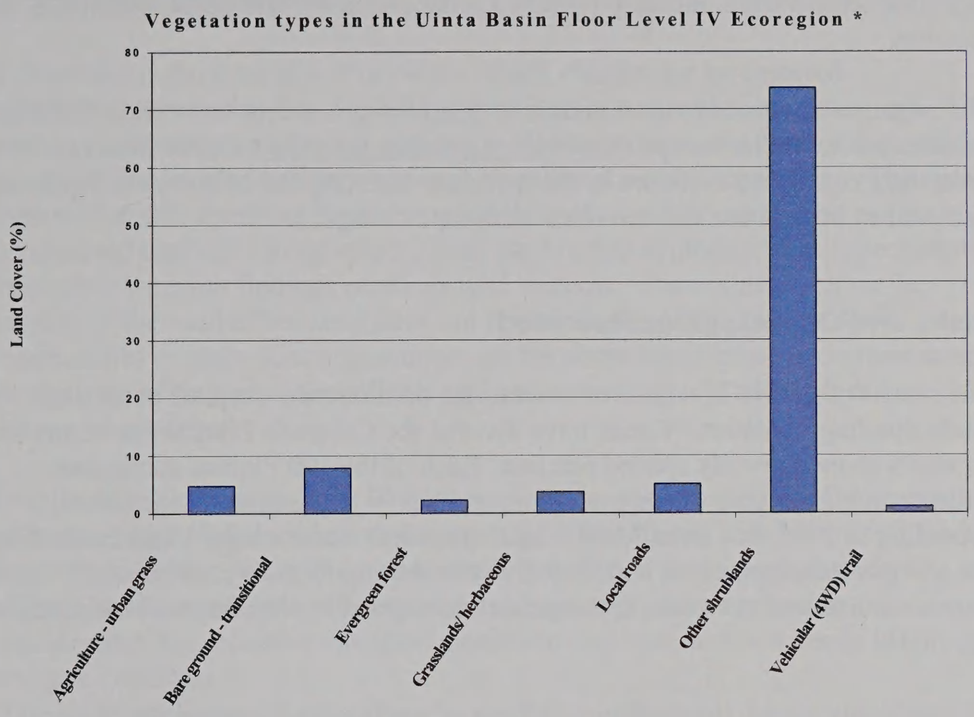

Figure 3. Fragmentation profile – Uinta Basin Floor Ecoregion

Significant Agents or Vectors of Change

Both natural and anthropogenic activities fragment landscapes. Natural drivers of fragmentation may include seismic activity, vegetation type, topography, climate and hydrologic features. Anthropogenic drivers of fragmentation include variations in land use practices, recreation, grazing, oil and gas exploration, mining, housing and urban development and trails. Of all anthropogenic activities over which managers may exert control, road construction and use can be considered the most significant driver of fragmentation (Saunders 2001; Baker 2000; Forman 2000; Spellerberg 1998; Forman 1995). Roads are a widespread and dominant feature on the landscapes of the United States and the negative impacts of roads are well documented (see Trombulak and Frissell, 2000 and Spellerberg, 1998).

Trombulak and Frissell (2000) conducted an extensive review of the literature and have identified seven general ways in which roads affect ecosystems: (1) increased mortality from road construction, (2) increased mortality from collision with vehicles, (3) modification of animal behavior, (4) alteration of the physical environment, (5) alteration of the chemical environment, (6) spread of exotic species, and (7) increased alteration and use of habitats by humans. Roads are the primary mechanisms by which human access the landscape and can be considered a basic indicator of human use and influence on the environment. Another principle effect of roads is the expansion of high contrast edge habitats (McGarigal, personal communication). Edge habitats along roads create microclimatic changes, including increased evaporation, increased temperature, increased incident solar radiation, and decreased available soil moisture.

The negative effects of roads combine to degrade ecosystems and create unsuitable habitats across the landscape (http://www.cpluhna.nau.edu/). Input from resources specialists confirmed evidence in the literature asserting the existence of roads is an indicator of human use and driver of landscape change.

Risks and Opportunities Revealed

The results of the NSTC resource assessment demonstrate a typical pattern of landscape fragmentation. Roads have divided the Colorado Plateau into many small, regularly shaped, evenly spaced patches. Each of the 100 Plateau ecoregions indicates a high degree of fragmentation and heavy human use. For instance, according to 2001 data over 7,000 oil and gas wells occur on the Uinta Basin Floor. Oil and gas development is undoubtedly contributing to mule deer habitat fragmentation road networks are expanded to support exploration and maintenance activities.

As previously stated, the ecological effects of roads extend beyond the physical limits of a road into the road effect zone where mule deer habitat may be negatively affected (Hanley 1996). High road densities will expand the road effect zone further, potentially making even quality habitat resource unsuitable to some shrubland species such as mule deer. Data on the level of use for each road type is needed to establish cause and effect relationships between the road effect zone and natural processes of shrub communities.

Kie et al. (2002) demonstrated the amount of vegetative edge is inversely related to mule deer home range size. Mule deer habitat with low vegetative edge to area ratios (a regular shape) correlates with larger mule deer home ranges and smaller populations. Larger amounts of high-contrast edge and the associated road effect zone may potentially make quality habitat unavailable to mule deer. Year-long habitat within the Uinta Basin exhibits both of these conditions.

Fragmentation by roads may therefore affect the size of mule deer home range regardless of habitat quality, particularly in highly fragmented habitats. Our regional analysis identifies the Uinta Basin-Floor as both a highly fragmented ecoregion and habitat type. The USGS remoteness model shows areas within the Basin most isolated from roads, providing mule deer habitat less affected by road-induced fragmentation. Further analysis of the Basin, its vegetative cover and habitat condition may reveal mule deer management opportunity.

Information Thresholds

A threshold is the limit above or below which change can be detected. Information thresholds develop and support best management practices. NSTC is not in a position to recommend mitigation efforts because of a lack of quantifiable threshold data needed to apply regional assessment data to local areas. The data presented in this synthesis represent a baseline of resource conditions, not a trend or threshold analysis. Road effect zones used in this synthesis were approximated from other research findings of shrub-land systems. Current research on the impacts of the road effect zone does not reveal thresholds specific to shrub communities or mule deer populations. In the absences of cause and effect data, the analysis of fragmentation effects and associated impacts on target resources can not be predicted.

Despite these data limitations, BLM managers can begin to address fragmentation by continuing to develop their understanding of conditions and drivers that lead to fragmented landscapes, and the commensurate effects on ecological systems. Mitigating fragmentation will require a regional approach to resource management that monitors changes in baseline data and assesses trends in resource condition.

Gaps in Science Information

Staff at NSTC identified several significant gaps in existing data that may hinder a regional resource assessment approach. These data gaps limited the synthesis to an analysis of baseline conditions and negated the possibility of recommending mitigation efforts. The lack of "pre road" vegetation data is most significant. NSTC was unable to assess changes in vegetative composition induced by roads. The analysis was limited to a dataset reflecting vegetation condition after roads were established. Change analysis is not possible without data representing vegetative condition before roads were established.

Data on the level, timing and season of use for each road type is needed to understand the impact of the road effect zone on plant communities. Current road inventories at the regional scale are missing significant data including location, level and season of use, and management designations.

Detailed wildlife habitat condition information and species-specific home range data are needed to assess the impact of road effect zones on habitat quality. The habitat data used in this synthesis are broad-scaled, based largely on the best estimate of local wildlife specialists. The GAP and National Land Cover Dataset are insufficient to establish habitat types; more resolute data are unavailable for the region. Broad-scale habitat data should be augmented with home range data.

Obviously, these gaps can be overcome by prioritizing regional management issues and leveraging resources to collect the needed data.

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CHAPTER 3: APPLICATIONS OF REGIONAL INFORMATION

This chapter contains a report on the process used and results of two test applications of Colorado Plateau resource assessment information. The applications tested were designed to address the Colorado Plateau Manager's Group (CPMG) question:

How can BLM managers mitigate landscape fragmentation on the Colorado Plateau?

Significant time and effort was invested by the NSTC to develop and present relevant information in a format that would be helpful to Colorado Plateau decision-makers wrestling with this question. The first applications test provides a relative picture and baseline of landscape fragmentation throughout the Colorado Plateau.

Colorado Plateau resource managers can mitigate landscape fragmentation by discontinuing activities that cause fragmentation. To be effective, resource managers need to know where landscape fragmentation is potentially a resource of concern. The second applications test was designed to investigate the impact of landscape fragmentation on mule deer habitat. Potential habitat fragmentation risks and mitigation opportunities are discussed.

A geographic information system (GIS) and fragmentation software are used to display resource data in a fragmented landscape context. Presumably any resource of concern can be overlain in the fragmented landscape context as long as the resource data is available digitally. Additional analyses are possible.

Fragmentation versus Conversion

Before describing and discussing the two applications tests we need to address a definition question posed by the CMPG:

What is the difference & relationship between habitat fragmentation and conversion?

Fragmentation – sometimes discussed as 'habitat fragmentation' or 'landscape fragmentation' – is a shift in distribution, composition and configuration of patch types. Fragmentation commonly results in a reduction in land cover types, and an apportionment of the remaining types into smaller, more isolated patches (Noss and Csuti 1997).

Habitat and landscape conversion implies a change from one habitat, community or ecosystem type to another. Conversion can be both a cause and effect of fragmentation. Fragmented landscapes may be less resilient to change or less resistant to invasion by non-native species. For example, many exotic plants, insects, and fungal diseases of trees are known to disperse and invade ecosystems in the western US via roads and vehicles (Saunders et al. 1991; Schowalter 1988). Conversion can also result from management activities that fragment landscapes by replacing one type of land cover with another. For example, conversion of forest to agriculture production often results in a remnant, isolated strip of forest vegetation along the perimeter of agricultural landscapes.

NSTC did not address the questions of conversion specifically because data necessary for the analysis is not available. Two types of data are needed to address conversion: 1) predevelopment vegetation data and 2) land use history (including treatments, natural events, etc). Assuming the data exists, such data collection efforts would have required significant time from Field Office staff.

EPA's Environmental Sciences division, Landscape Characterization Branch in Las Vegas agreed to provide a preliminary assessment of conversion by analyzing thematic map images to document vegetative change. This assessment of change would highlight areas of conversion and help identify where a management activity occurred. The lack of historic vegetative data would limit our understanding of *what* change has occurred in the highlighted areas. Due to circumstances beyond our control, EPA was unable to meet the project deadline. And the change analysis is not included in the regional resource assessment.

Managers may wish to support research addressing the conditions and effects related to landscape conversion. The information gaps surrounding historical management activities and historical vegetative conditions will continue to be an obstacle to understanding landscape fragmentation and conversion. The following sections address an application of regional resource information to characterize landscape fragmentation.

Colorado Plateau Roads and Landscape Fragmentation

As discussed in Chapter 2, roads fragment the landscape more than any other human activity (Saunders 2001; Baker 2000; Forman 2000; Spellerberg 1998; Forman 1995), so NSTC staff concentrated on obtaining road information and evaluating its accuracy and applicability. Other fragmentation causative activities were not explored.

Regional resource data were examined to understand the influence of roads on landscape composition and configuration across the Colorado Plateau. Marked differences in data quality caused difficulty in integrating these regional data layers. Despite the data discrepancies, NSTC staff was able to analyze the data using the spatial-pattern analysis software FRAGSTATS. NSTC called on specialists from USGS Biological Resources and National Mapping Divisions, EPA, BLM and academia to review our approach, assumptions, critical questions and indicators.

Changing landscape patterns are of increasing concern to land managers because the spatial relationships between landscape features can strongly influence ecosystem function. We generally consider landscapes in terms of big things – watersheds or basins. The relevant definition of a landscape actually depends on the species, ecological function or phenomenon in question (McGarigal and Marks, 1995). For example, a hawk views its environment at a different scale than a mouse. Landscapes may also be divided into patches, which are also defined relative to the issue. If we are interested in distribution of exotic plant species, we could examine patches of that species or patches of native species being displaced.

Landscape fragmentation produces effects that can be both observed and quantified. They include:

- shifts in distribution, composition and configuration of patch types;
- reductions in patch type; and
- apportionment of the remaining communities into smaller, more isolated patches.

Fragmenation can occur in two general ways: 1) inherent, or natural fragmentation and 2) induced, or human-caused fragmentation. It is important to understand the inherent (natural) fragmentation of the landscape in question before examining human-induced fragmentation. Identification of distinct ecoregions provides an excellent basis for an analysis of inherent fragmentation. Ecoregions can be used for stratifying the landscape into units with similar environmental parameters and responses to management (Dahms and Geils 1997). Since ecoregions are differentiated by both biotic and abiotic factors, the natural distribution and composition of ecoregions can describe the inherent fragmentation of a landscape. We sought to answer four critical questions about landscape fragmentation on the Colorado Plateau:

- What is the composition and configuration of each landscape?
- What is the inherent degree of fragmentation?
- What are the current road densities and edge effects zones?
- What is the road induced degree of fragmentation?

Scale

After identifying the issue and key questions, analysts should determine the boundary and scale of analysis. We defined the extent, or outer boundary, of our landscape using Colorado Plateaus Level III ecoregion boundary[4] (Omernik, 1995). Ecoregions are areas that may be defined hierarchically at a range of scales to serve as a spatial

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[4] Included within the Level III Colorado Plateaus boundary are a number of Level III Rocky Mountain ecoregions. The Rocky Mountain ecoregions (including the Abajo, Henry, Navajo and La Sal Mountains) were omitted from this analysis because they represent distinctly different ecological zones that warrant separate analysis.

framework for broad research, assessment, monitoring and management of ecosystems (Woods et al. 2001).

We used Omernik's Level IV ecoregions (Figure 2) as analysis units. For assessments of forested landscapes, Heilman et al. (2002) and Trombulak and Frissell (2000) state that units of analysis should be defined according to the primary driver of fragmentation. Our analysis assumes roads as the primary indicator of landscape condition and driver of fragmentation. The landscape characteristics and road densities of our study differ significantly from the forested landscapes in Heilman, et al. and Trombulak and Frissell. We attempted to define analysis units by using roads as the boundaries but concluded the resulting units were too large for rapid analysis. For these reasons, Level IV ecoregions were deemed more appropriate.

Other landscape boundaries representing a jurisdictional approach were considered and may better reflect management boundaries. However, jurisdictional boundaries do not necessarily correspond with ecological structure or resource condition. We maintained an ecoregional approach to our analysis in order to emphasize the need for cross-jurisdictional management of landscapes, to extend our understanding of ecosystems and to facilitate data collection.

Data

As discussed in Chapter 2, we compiled an inventory of existing data (Appendix A) on the Colorado Plateau, which included a review of scientific literature, web resources, and regional datasets. We integrated and modified several preexisting national, state and local datasets to create a regional dataset (Appendix B). Four steps were used to develop a regional land use dataset consisting of landcover, roads, and energy development as a basis for analysis of fragmentation:

- *Set parameters for extent and grain of the landscape:* The critical element in defining landscape parameters was in choosing the resolution of data we would use. National Land Cover Data (NLCD) resolution determined our lower limit of 30m. We considered resampling the data at coarser resolutions, but our challenge was to determine a resolution that would reasonably capture the area of road effects on the landscape. As mentioned previously, the road-effect zone may be many times wider than the road itself. We were faced with choosing a data resolution that captured physical roads as well as an average road-effect zone. After reviewing the literature on the impacts of roads and edge effects, we estimated a 60 m^2 resolution to quantify the road effects zone (refer to the discussion in Chapter 2).

- *Assess data quality and vintage:* The USGS EROS Data Center (EDC) provided access to the data dictionaries for 1:100,000- and 1:24,000-scale digital line graphs (DLG) and digital orthophoto quadrangles (DOQs) at fttp://edc.usgs.gov/pub/metadata. The data dictionary fields were added as attributes to 1:100,000- and 1:24,000-scale quadrangle indexes for analysis in

ArcView3.2. U.S. Geological Survey DLG and GDT data contain continuous coverage at the 1:100,000-scale over the Colorado Plateau ecoregion. More than one thousand 1:24,000-scale DLG quadrangle maps cover the Colorado Plateau ecoregion, but neither this nor the DOQs are continuous over the ecoregion. The existing coverage represents only 80% of the ecoregion (Figure 4). The GDT road metadata contains a range of dates, however it was not clear how the dates apply to any given area represented by the dataset. GDT was revised more recently in some but not all areas, but is less spatially accurate than the DLGs.

The source dates for 1:100,000-scale DLG and DOQs were found to provide a reliable representation of the vintage of material upon which the data was derived. The source dates for 1:24,000-scale DLG were less reliable in representing the vintage of source material due to map revisions, which are not part of the data dictionary field. DLG dates range from 1949 to 1994 or else no data was available, and the median age of most road data used exceeds 14 years. We ultimately used TIGER2000, USGS GDT and DLGs compiled from 1:100,000-scale maps to construct a road dataset.

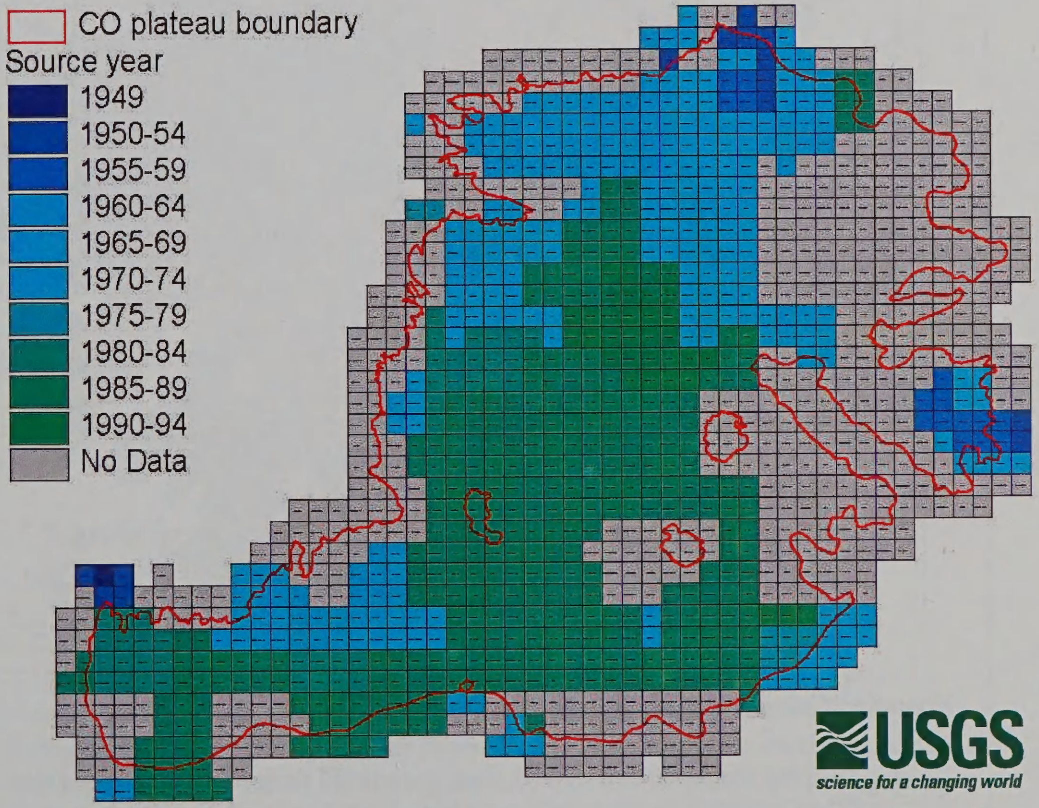
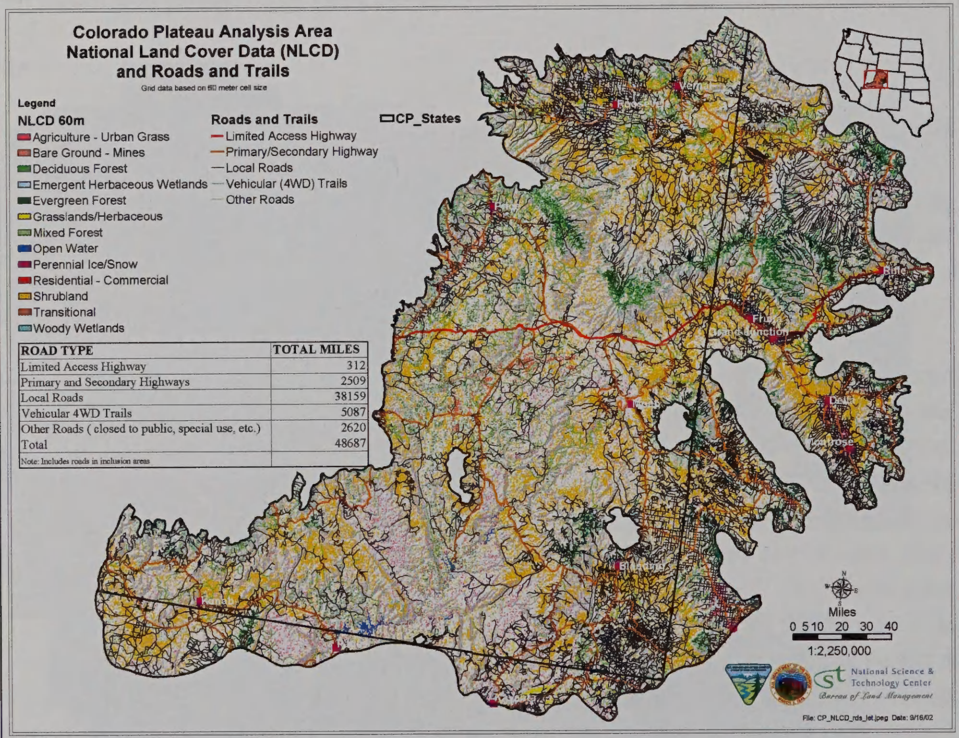


Figure 4. Regional road data availability

- *Integrate multiple data layers:* We integrated and modified several pre-existing spatial datasets to derive both intermediate and final layers. All landcover data was converted to $60m^2$ pixels and projected to the Albers equal area NAD27 projection. From this data, we were able to:
    - refine the existing cover types using 1992 NLCD, GAP Analysis Program and USGS SAGEMAP data;
    - reclassify cover types into coarse groupings for analysis: deciduous forest, evergreen forests, grasslands, mixed forest, shrubland, emergent wetlands, woody wetlands, open water, bare ground, transitional, agriculture, and residential;
    - create a composite landcover-road dataset incorporating 60m road-effects zone (Figure 5);
    - create a composite dataset of oil and gas well sites in the region (Figure 6); and
    - analyze landscape fragmentation of Level III and IV ecoregions to obtain information on composition and configuration with and without roads.



ROAD TYPE	TOTAL MILES
Limited Access Highway	312
Primary and Secondary Highways	2509
Local Roads	38159
Vehicular 4WD Trails	5087
Other Roads (closed to public, special use, etc.)	2620
Total	48687
Note: Includes roads in inclusion areas	

Figure 5. Colorado Plateau analysis area

- *Analyze fragmentation:* We used the spatial pattern analysis program FRAGSTATS (McGarigal and Marks, 1995) to examine landscape patterns of the ecoregion. We used simple statistics to describe the Colorado Plateau landscape and more complex metrics for describing composition and configuration. Appendix I lists the metrics used and their descriptions.

Fragmentation usually affects the distribution of a focal class (i.e., a specific patch type). However, we also considered how roads are affecting the composition and configuration the entire landscape mosaic without reference to a focal class. We conducted an analysis of fragmentation for level III ecoregions, level IV ecoregions and landcover classes.

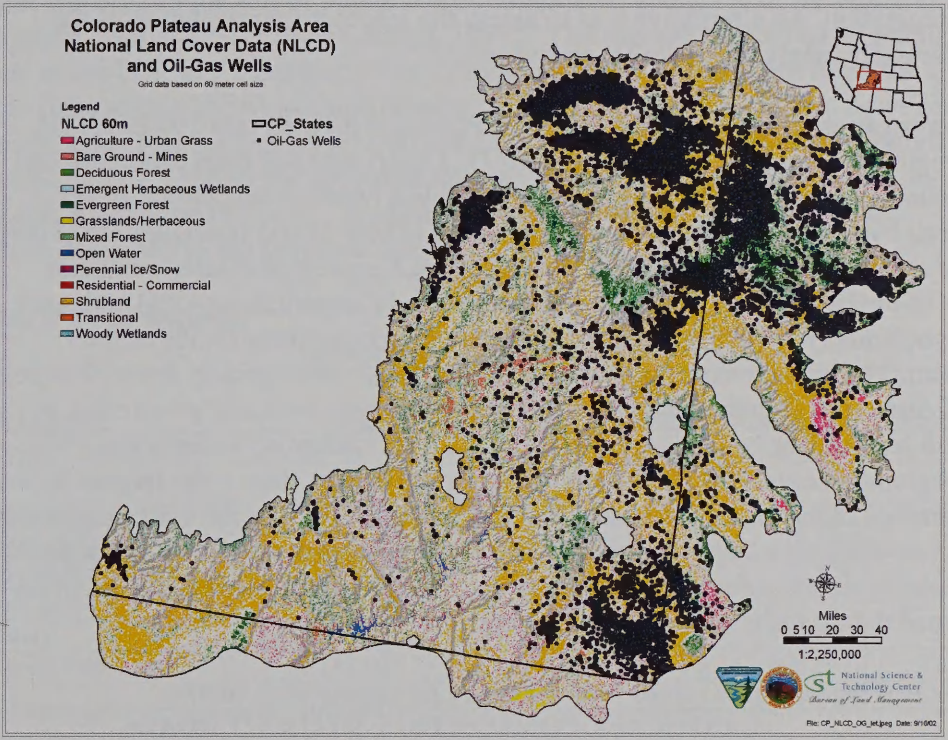


Figure 6. Oil and gas well locations

Results and Discussion

We analyzed the integrated dataset to answer four critical questions about the composition and configuration of the Colorado Plateau:

- What is the composition and configuration of each landscape?
- What is the inherent level of fragmentation?
- What are the current road densities and edge effects zones?
- What is the road induced level of fragmentation?

Vegetative composition and configuration: We analyzed baseline composition and configuration of vegetative cover types on the Plateau and created a database of cover types for each Level IV ecoregion. An example is provided in Figure 3. The results indicate that shrub communities are the dominant vegetative cover on the Plateau. These profiles provide insight to the way cover types are distributed across the landscape and how they are related to roads. As road data and vegetative data are updated, managers will be able to track changes in vegetative responses to roads and the distribution, composition and configuration of each ecoregion.

We lacked a "pre-roads" vegetative dataset for the Plateau making changes in composition and configuration of cover types difficult to assess. Assessment of vegetative cover without a road data layer and with a road data layer does not fully convey the degree to which roads have affected the composition and configuration of the vegetation. An alternative was to assess the inherent fragmentation of the landscape by analyzing level IV ecoregions.

Inherent fragmentation: The Colorado Plateau is divided into 100 Level IV ecoregions comprising 8 classes (Figure 2). Descriptions of each ecoregion can be found in Appendix H. We sought to provide a baseline description of the Plateau by quantifying landscape composition (Table 1) and configuration (Table 2) of each ecoregion without roads. Two of the 8 ecoregion classes comprise 58% of the landscape – Semiarid Benchlands and Canyonlands (45%) and Arid Canyonlands (13%). The largest single ecoregion comprises 13.5% of the Plateau. The average ecoregion area is 122 km^2, but varies widely from 20 to over 1000 km^2. The average distance to the nearest ecoregion of any given class is over 8 km ranging in distance from 37 km to 2 km. Monticello Uplands ecoregions is comprised of 51 individual patches of that class – the largest occurrence in the region. The shape of the ecoregions across the Plateau is highly irregular creating a large amount of natural edge across the region. Composition and configuration information provides us a baseline for detecting change when the road data layer is added to the analysis.

Table 1. Fragmentation results (without roads) for composition metrics.

LANDSCAPE COMPOSITION WITHOUT ROADS				
Ecoregions	**% of Landscape**	**Patch Number**	**Patch Density**	**Largest Patch Index**
Monticello Upland–Desert Shrublands	8.06	51	4.04E-04	2.04
Shale Deserts	9.55	3	2.37E-05	9.48
Semiarid Benchlands & Canyonlands	44.97	29	2.30E-04	13.56
Arid Canyonlands	12.94	3	2.37E-05	12.68
Escarpments	11.67	5	3.96E-05	8.69
Uinta Basin Floor	6.08	1	7.91E-06	6.08
Northern Uinta Basin Slopes	1.43	1	7.91E-06	1.43
Sand Deserts	4.26	7	5.54E-05	2.28

Table 2. Fragmentation results (without roads) for configuration metrics.

LANDSCAPE CONFIGURATION WITHOUT ROADS						
Ecoregions	**Total Edge (m)**	**Edge Density**	**Mean Area (m^2)**	**Area Coeff. of Variation**	**Shape Index**	**Nearest Neighbor (km)**
Monticello Upland–Desert Shrublands	5,346,720	0.42	20,165.99	220.12	2.10	2.40
Shale Deserts	2,196,480	0.17	406,344.36	139.80	3.01	37.22
Semiarid Benchlands & Canyonlands	13,019,340	1.03	197,967.48	219.03	2.78	2.06
Arid Canyonlands	4,607,940	0.36	550,672.80	137.17	4.84	22.03

Escarpments	3,109,560	0.25	298,023.19	138.00	3.79	23.23
Uinta Basin floor	734,400	0.06	776,794.68	0	2.08	0
N. Uinta Basin Slopes	192,840	0.02	183,033.00	0	2.06	0
Sand Deserts	1,598,880	0.13	77,748.27	118.92	2.41	21.91

Road densities: We calculated road densities for all Federal and non-Federal lands within the Colorado Plateau to compare to the national average. The United States has 6.2 million-km of public roads, comprising about 1% of the entire U.S. landscape (National Research Council, 1997). The average density of all public roads in the U.S. is 1.2 km/km^2. The Colorado Plateau's 75,000 km of public roads represents a below average density of approximately 0.6 km/km^2 however, specific estimates for sub-regions do not exist to compare against other western regions. Table 3 shows the approximate road densities for all Federal and non-federal lands in the Plateau. These calculations are based on the same road dataset described in the previous section.

Table 3. Road densities.

ROAD DENSITY BY LAND OWNER						
Land Owner	**Acres**	**Area (km^2)**	**% of Plateau**	**Road Length (m)**	**Miles**	**Density (m/km^2)**
Bureau of Indian Affairs	3,454,388	13,980	11.1	10,355,734	6,435	741
Bureau of Land Management	16,886,266	68,338	54.1	31,797,785	19,758	465
Bureau of Reclamation	159,843	647	0.5	28,746	18	44
Fish and Wildlife Service	14,086	57	0.0	56,824	35	997
Forest Service	2,411,234	9,758	7.7	3,679,924	2,287	377
Military	73,870	299	0.2	130,379	81	436
National Park Service	1,112,005	4,500	3.6	608,897	378	135
Private	7,107,832	28,765	22.8	28,298,273	17,584	984

ROAD DENSITY BY FIELD OFFICE						
Field Office	**Acres**	**Area (km^2)**	**% of Plateau**	**Road Length (m)**	**Miles**	**Density (m/km^2)**
Arizona Strip	1,299,452	5,259	4.2	2,395,276	1,488	455
Cedar City	3,926,671	15,891	12.6	5,634,397	3,501	355
Glenwood Springs	422,875	1,711	1.4	1,631,883	1,014	954
Grand Junction	1,835,941	7,430	5.9	5,569,176	3,460	750
Gunnison	24,544	99	0.1	83,433	52	840
Little Snake	377,144	1,526	1.2	693,915	431	455
Moab	2,676,097	10,830	8.6	4,572,953	2,841	422
Monticello	4,533,254	18,346	14.5	10,463,809	6,502	570
Phoenix	867,286	3,510	2.8	2,647,785	1,645	754
Price	3,521,897	14,253	11.3	6,482,412	4,028	455
Richfield	2,359,396	9,548	7.6	2,771,082	1,722	290
Salt Lake	62,914	255	0.2	158,540	99	623
San Juan	1,239,386	5,016	4.0	4,464,302	2,774	890
Uncompahgre Basin	1,748,450	7,076	5.6	7,510,625	4,667	1,061
Vernal	4,115,210	16,654	13.2	12,481,240	7,755	749
White River	2,208,655	8,938	7.1	7,393,870	4,594	827

A road density map (Figure 7) was compiled based on existing data and provides a rough estimate of where fragmentation and roadless areas are greatest. Forman (2000) demonstrated that while only 1% of the United States is comprised of roads, 19% of the total area of the US is ecologically affected by roads. We employed Forman's calculation at a finer scale to determine the amount of the Plateau ecologically affected by roads. Road attributes in our dataset are largely undifferentiated whereas Forman classified roads and road effects based on these classifications. We assumed a 60m road effect zone resulting in 5 percent of the Plateau ecologically affected by roads. Forman used a significantly higher estimate for road effect zones (200 to 800 meters). Our estimate will become more accurate as road attributes are more clearly differentiated and specific road effect zones are applied to the various road classes. Adding the road data layer, we conducted an analysis of the 100 ecoregions.

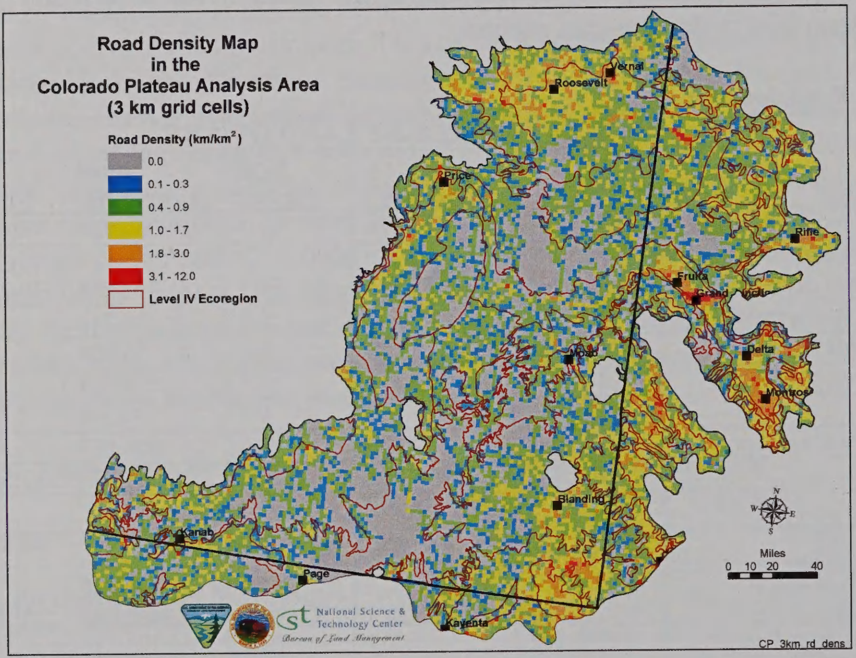


Figure 7. Road densities

Induced fragmentation: We again analyzed landscape composition (Table 4) and configuration (Table 5). Relationships generally remained constant, but the percentage of the landscape occupied by each of ecoregion decreased. Table 4 shows roads occupy 4.35% of the landscape – an area greater than the Sand Desert ecoregion. The average area of each patch is reduced to 0.6 km^2 and is less variable than previously demonstrated. The largest patch on the landscape now comprises only 4.56% of the total area of the Plateau. The average distance to the nearest ecoregion declined from over 8.0 km to 0.1 km. The total number of patches has increased across all ecoregions. When separated by roads, the number of distinct ecoregions increases from 100 to more than 16,000. The shapes of each of these ecoregions resemble a square.

Results suggest change in both composition and configuration induced by roads. More than 174,000 km of road-induced edge occurs on the landscape.

Table 4. Fragmentation results (with roads) for composition metrics.

LANDSCAPE COMPOSITION WITH ROADS				
Ecoregions	**% of Landscape**	**Patch Number**	**Patch Density**	**Largest Patch Index**
Monticello Upland–Desert Shrublands	7.55	3,573	0.0283	0.11
Shale Deserts	9.11	3,720	0.0294	0.68
Semiarid Benchlands & Canyonlands	43.69	5,702	0.0451	1.33
Arid Canyonlands	12.66	2,053	0.0162	4.56
Escarpments	11.47	809	0.0064	2.64
Uinta Basin Floor	5.75	2,034	0.0161	0.68
Northern Uinta Basin Slopes	1.34	464	0.0037	0.05
Sand Deserts	4.08	1,339	0.0106	0.20
Roads	4.35	337	0.0027	4.27

The number of ecoregion occurrences increased as much as 200,000% - from 1 patch to more than 2,000 (Table 5). The patch density increased across all ecoregions, the greatest increase occurring in Uinta Basin-Floor and Sand Desert ecoregions. The percent of the landscape occupied by each ecoregion decreased marginally, but the largest patch of any ecoregion decreased at least 60%. The average area of each ecoregion patch decreased nearly 100%. These results demonstrate a typical landscape fragmentation pattern: increase in high contrast edge; division of intact landscapes into small, regularly shaped patches; reduction in patch area as the road effect zone increases. The degree to which roads fragment each ecoregion depends on the metric analyzed and it is the magnitude of change that is most striking. Without time series data depicting vegetative change it is difficult to measure patch isolation. However, patches may be functionally isolated by the road-induced edge, which introduces a high contrast barrier between patches.

Table 5. Fragmentation results (with roads) for configuration metrics

LANDSCAPE CONFIGURATION WITH ROADS						
Ecoregions	**Total Edge (m)**	**Edge Density**	**Mean Area (m^2)**	**Area Coeff. of Variation**	**Shape Index**	**Nearest Neighbor (m)**
Monticello Upland–Desert Shrublands	28,346,940	2.24	267.07	286.58	1.56	124.26
Shale Deserts	23,225,160	1.84	309.40	716.86	1.43	120.31
Semiarid Benchlands & Canyonlands	82,974,720	6.57	968.15	595.70	1.65	120.08
Arid Canyonlands	21,091,260	1.67	779.13	1,735.83	1.53	120.14
Escarpments	16,259,640	1.29	1,791.20	757.10	1.68	120.25
Uinta Basin Floor	16,634,280	1.32	357.13	625.97	1.48	120.11
Northern Uinta Basin Slopea	4,720,560	0.37	363.75	251.09	1.62	120.03
Sand Deserts	10,593,360	0.84	385.01	444.15	1.50	120.05
Roads	175,529,760	13.89	1,631.54	1,797.61	4.99	713.58

Colorado Plateau Mule Deer Habitat Fragmentation

The landscape fragmentation results were overlain on mule deer habitat to create a visual representation of mule deer habitat fragmentation caused by roads. Deer habitat management can be considered landscape management because mule deer populations are indicators of landscape condition often responding negatively to changing landscape patterns (Hanley 1996).

Seasonal home range formed the analytical units for our habitat fragmentation analysis. The available data represents coarse-scale habitat types, excludes population data and herd size, and is incomplete for parts of the region. However, these data represent the best available regional information. Effects of roads on composition and configuration of each home range type were analyzed.

Table 6. Percentage of change on landscape composition and configuration.

LANDSCAPE COMPOSITION (PERCENT CHANGE)

Ecoregions	% of Landscape	Patch Number	Patch Density	Largest Patch Index
Monticello Upland–Desert Shrublands	-6.24	6,905.88	6,911.05	-94.66
Shale Deserts	-4.59	123,900.00	123,720.53	-92.84
Semiarid Benchlands & Canyonlands	-2.84	19,562.07	19,549.21	-90.22
Arid Canyonlands	-2.16	68,333.33	68,127.64	-64.02
Escarpments	-1.73	16,080.00	16,072.48	-69.62
Uinta Basin Floor	-5.51	203,300.00	203,319.44	-88.80
Northern Uinta Basin Slopes	-6.82	46,300.00	46,648.57	-96.57
Sand Deserts	-4.28	19,028.57	19,032.62	-91.05

LANDSCAPE CONFIGURATION (PERCENT CHANGE)

Ecoregions	Total Edge	Edge Density	Mean Area	Area Coeff. of Variation	Shape Index	Nearest Neighbor
Monticello Upland–Desert Shrublands	430.17	430.18	-98.68	30.19	-25.43	-94.81
Shale Deserts	957.38	957.38	-99.92	412.76	-52.56	-94.81
Semiarid Benchlands & Canyonlands	537.32	537.32	-99.51	171.97	-40.70	-94.17
Arid Canyonlands	357.72	357.71	-99.86	1,165.47	-68.39	-99.45
Escarpments	422.89	422.89	-99.40	448.64	-55.71	-99.48
Uinta Basin Floor	2,165.02	2,164.93	-99.95	0.00	-29.16	0.00
Northern Uinta Basin Slopes	2,347.92	2,347.80	-99.80	0.00	-21.00	0.00
Sand Deserts	562.55	562.52	-99.50	273.48	-37.55	-99.45

Mule deer are suitable indicators of landscape condition because they have relatively large and seasonally migratory home ranges (Nicholson et al. 1997). The diverse habitat requirements of mule deer encompass the needs of other species (Hanley, 1996), their biology is well known (Kie et al. 2002), and they are a valuable resource to people making them appealing for study at a broad scale. Hanley (1996) asserts that deer habitat management is landscape management because of the capacity to provide valuable information for land-use planning and resource management.

Changing landscape patterns are of increasing concern in managing mule deer habitat because the spatial relationships between habitat features can influence home range size (Kie et al. 2002). Changing patterns and habitat fragmentation produces effects that can be observed and quantified:

- Shifts in distribution, composition and configuration of habitat types.
- Reductions in the total amount of habitat.
- Apportionment of the remaining habitat into smaller, more isolated patches.

Home ranges are often small in areas of high natural edge density and irregular shapes (Kie et al. 2002). Whereas, small, regularly shaped patches of fragmented habitat may increase home range size (Kie et al., 2002 and Nicholson 1997). Deer population density is thought to be inversely related to home range size (Loft et al. 1991) leading us to conclude that fragmentation may result in smaller populations with larger home ranges.

Activities that fragment mule deer habitat are similar to those that can fragment landscapes. Induced fragmentation may result from various land use practices including urban expansion, road constructions, and oil and gas development. As with landscapes, roads can be considered a significant driver of habitat fragmentation. The principle effects of roads are the expansion of high contrast edge, a reduction in habitat quality, and avoidance behavior, especially within a 200 meters road effect zone (Trombulak and Frissell, 2000; Spellerberg, 1998; Rost and Bailey, 1979).

Scale

We defined the scale in terms of the Level III ecoregions described in the previous section. The ecoregion scale encompasses several types of mule deer habitat and is of sufficient size to capture both home range and migration movements. Seasonal home range (summer, winter, and year-long habitat) formed our analysis units for habitat fragmentation analysis. We did not use Level IV ecoregions as analysis units because we did not have access to vegetative data resolute enough to delineate habitat types within ecoregions. We considered defining habitat units by state-defined game or wildlife management areas. These management units are based on the economic value of wildlife and contain population data. However, the data in these units is inconsistent across state lines. We determined seasonal home range information to be the best available dataset for analysis units despite the fact that this data is not consistently available across all state boundaries.

Data

Mule deer home range information was obtained from the Utah Division of Wildlife Resources (UDWR), and the Colorado Division of Wildlife (CDOW). Home range information was not available from the State of Arizona and the Navajo Nation. These areas were excluded from our analyses. The Rocky Mountain ecoregions within the Colorado Plateau were also excluded from analysis. The available data represents coarse scale habitat types, and does not include information on populations or herd size. We modified and integrated several pre-existing datasets to create a regional habitat dataset (Appendix A). From these data layers we developed a regional habitat and land use map consisting of seasonal habitat (home range) types and roads as a basis of analysis (Figure 8). Four steps were used to develop the new habitat data layer:

- *Set parameters for extent and grain of the landscape:* The extent of the region was defined by Omernik's Level III ecoregion. The discrete seasonal habitat polygon (summer, winter, year-long habitat) served as our units of analysis. Unsuitable habitat comprised a large portion of the region and was analyzed in conjunction with suitable habitat.

- *Assess data quality and vintage:* We used the same road data as was used in the landscape analysis. Utah habitat data represents mule deer use areas as determined by UDWR field biologists during the late 1980s. Feature attributes were determined by field biologist with local knowledge of the geographic area and wildlife species use of the area. The data represents a best assessment based on their professional judgment. The data was intended for use at the 1:100,000 scale. The Colorado data was derived from CDOW district wildlife managers and biologists in 2001. Each habitat classification represents that part of the overall range where 90% of the individuals are located during the seasonal period. Mapped activity areas were drawn on maps of 1:50,000 scale.

- *Integrate multiple data layers:* We integrated and modified the pre-existing habitat datasets to derive a final layer. All datasets were converted to 1:100,000 scale. We reduced the total number of habitat descriptions to 4 consistent types: winter, summer, year-long, and unsuitable habitat. We made an effort to edge match habitat units across state boundaries where possible, but this effort was not entirely successful and demonstrates the difficulties of integrating data. With this baseline data we were able to:

    - Overlay the integrated road dataset.
    - Overlay the composite oil and gas well dataset.
    - Analyze landscape fragmentation of Level III and habitat types to obtain information on composition and configuration with and without roads.

- *Analyze fragmentation:* We used FRAGSTATS (McGarigal and Marks, 1995) to quantify habitat composition and configuration across region. We analyzed how roads affect composition and configuration of the habitat types. FRAGSTATS produced results for habitat type and Level III Ecoregion in tabular format.

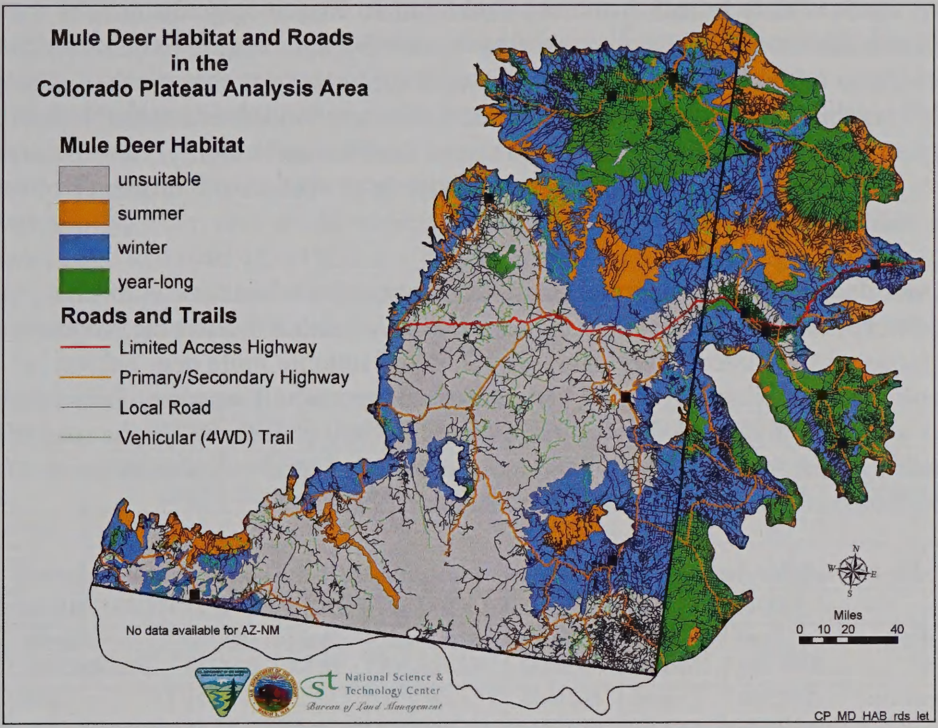


Figure 8. Mule deer habitat fragmentation

Results and Discussion

We analyzed the integrated dataset to answer four critical questions about inherent and induced fragmentation of mule deer habitat:

- What is the inherent degree of habitat fragmentation?
- What are the current road densities and edge effects zones?
- What is the road induced degree of fragmentation?
- How does fragmentation affect mule deer habitat?

Table 7. Habitat fragmentation results (without roads) for composition metrics

MULE DEER HABITAT COMPOSITION WITHOUT ROADS				
Habitat Type	**% of Landscape**	**Number of Patches**	**Patch Density**	**Largest Patch Index**
Unsuitable	38.95	107	0.0009	37.93
Summer	11.46	156	0.0013	4.19
Winter	30.88	91	0.0008	11.14
Yearlong	17.62	39	0.0003	9.35

Inherent fragmentation: We analyzed the inherent fragmentation of mule deer habitat by analyzing the degree to which the region is divided into four habitat types (Figure 8). We quantified composition (Table 7) and configuration (Table 8) for each habitat type. A large portion of the Plateau – 39% – is comprised of unsuitable habitat. Excluding unsuitable habitat, winter habitat represents the largest single patch on the landscape at 11%. The average patch area is 30 km^2, but varies widely from 8.7 to more than 53 km^2. The average distance to the nearest habitat patch of any given class is over 3.0 km ranging in distance from 0.8 km to 6.0 km. Each habitat type is well connected to other patches of that type, except for one patch of year round habitat embedded in unsuitable habitat type. The shape of the habitat types across the Plateau is highly irregular creating a high density of natural edge. The next step is to observe the influence of roads on habitat edge.

Road densities: We analyzed the same integrated road dataset as for the landscape analysis. Road density calculations remain the same for jurisdictional regions on the Plateau. We calculated 2.5% of suitable mule deer habitat is ecologically affected by roads - assuming a 60m road-effect zone. However, our review of the literature demonstrates that 60m may underestimate the road effect zone for deer, particularly in landscapes dominated by shrub communities (Nicholson et al., 1997 and Rost and Bailey, 1979).

Table 8. Habitat fragmentation results (without roads) for configuration metrics

MULE DEER HABITAT CONFIGURATION WITHOUT ROADS

Habitat Type	Total Edge (m)	Edge Density	Mean Area (m^2)	Area Coeff. of Variation	Shape Index	Fractal Analysis	Nearest Neighbor (km)	Contagion	Division
Unsuitable	5,482,080	0.46	43,216.16	1,002.32	1.72	1.21	6.04	1.00	0.86
Summer	7,345,440	0.62	8,719.48	489.78	2.00	1.18	2.35	0.99	1.00
Winter	12,051,420	1.02	40,279.93	425.46	1.96	1.19	0.85	0.99	0.98
Yearlong	6,254,940	0.53	53,632.00	345.97	2.53	1.16	4.90	0.99	0.99

Induced fragmentation: We conducted the same analysis of the 4 habitat types with a road data layer overlaid. We analyzed landscape composition (Table 9) and configuration (Table 10). Relationships generally remain constant, but the percentage of the landscape occupied by each of ecoregion decreased. The average habitat patch size is reduced to 0.6 km^2 and is less variable than previously demonstrated. The largest patch of suitable habitat on the landscape now comprises only 1.1% of the total area of the Plateau. The average distance to the nearest patch has also declined from over 6.0 km to 0.1 km. When separated by roads, the number of distinct habitat patches increases from 100 to over 12,000. The shape of each habitat patch resembles a square, reducing the importance of natural edge.

Table 9. Habitat fragmentation results (with roads) for composition metrics

MULE DEER HABITAT COMPOSITION WITH ROADS

Habitat Type	% of Landscape	Number of Patches	Patch Density	Largest Patch Index
Unsuitable	38.16	5,294	0.0451	7.94
Summer	11.10	1,660	0.0141	0.97
Winter	29.78	5,278	0.045	1.10
Yearlong	16.61	6,004	0.0511	0.58
Roads	4.36	324	0.0028	4.28

The degree of change in both composition and configuration induced by roads is substantial (Table 11). Year-long habitat shows the greatest percent change across all metrics indicating a high degree of fragmentation has occurred in this habitat type. More than 174,000 km of high contrast, road-induced edge has been added to the Plateau, increasing the amount of poor quality habitat. The road effect zone also causes an avoidance behavior in mule deer reducing the amount of available habitat. Nicholson et al. (1997) demonstrated home range size is positively related to the amount of poor quality habitat more than the amount of high quality habitat. Consequently, when deer avoid negative features of the environment – such as high contrast edge and road effect zones – they may also be avoiding high quality resources within that area. Fragmentation by roads may affect the size of mule deer home range regardless of habitat quality, particularly in highly fragmented habitats.

Table 10. Habitat fragmentation results (with roads) for configuration metrics.

MULE DEER HABITAT CONFIGURATION WITH ROADS

Habitat Type	Total Edge (km)	Edge Density	Mean Area (m^2)	Area Coeff. of Variation	Shape Index	Fractal Analysis	Nearest Neighbor (m)	Division
Unsuitable	50,839	4.33	846.32	1,831.56	1.47	1.17	200.22	0.99
Summer	25,453	2.17	784.87	556.29	1.77	1.21	204.74	1.00
Winter	65,335	5.56	662.38	479.04	1.64	1.19	125.55	1.00
Yearlong	50,247	4.28	324.85	546.53	1.54	1.19	122.48	1.00
Roads	163,442	13.92	1,579.43	1,765.86	4.81	1.84	681.54	1.00

Table 11. Percentage of change on habitat composition and configuration.

MULE DEER HABITAT COMPOSITION (PERCENT CHANGE)

Habitat Type	% of Landscape	Number of Patches	Patch Density	Largest Patch Index
Unsuitable	-2.04	4,847.66	4,911.11	-79.07
Summer	-3.16	964.10	984.62	-76.91
Winter	-3.57	5,700.00	5,525.00	-90.12
Yearlong	-5.73	15,294.87	16,933.33	-93.84

MULE DEER HABITAT CONFIGURATION (PERCENT CHANGE)

Habitat Type	Total Edge	Edge Density	Mean Area	Area Coeff. of Variation	Shape Index	Fractal Analysis	Nearest Neighbor	Division
Unsuitable	827.38	837.61	-98.04	82.73	-14.68	-2.79	-96.69	15.72
Summer	246.51	250.32	-91.00	13.58	-11.24	2.64	-91.28	0.19
Winter	442.13	448.11	-98.36	12.59	-16.21	0.53	-85.15	2.00
Yearlong	703.32	712.20	-99.39	57.97	-39.19	2.78	-97.50	1.03

Vegetative fragmentation: We applied the vegetative cover type analysis conducted for landscape fragmentation to mule deer habitat. We analyzed baseline composition and configuration of cover types on the Plateau. The vegetative edge density and road-induced edge density are of particular application. Figure 9 shows ecoregions from highest to lowest vegetative edge density – the boundary between vegetative types. The amount of vegetative edge density is inversely related to home range size (Kie et al. 2002). When combined with additional metrics, we can infer those regions with lower edge density may have larger home range. Those ecoregions with low vegetative edge density, high road-induced edge density (fragmentation), and a low shape index (Table 2) may represent areas of management concern. Much of the year-long habitat has low edge densities and low shape index – a condition correlated with large home range size. Year-long habitat also demonstrates the highest degree of fragmentation – a condition correlated with larger home range size. Since home range size is inversely related to population density (Loft et al. 1991), habitat fragmentation may create effects that place negative pressures on mule deer populations.

Regional Land Use Planning Tool

In collaboration with the U.S. Geological Survey (USGS) National Mapping Division, Rocky Mountain Mapping Center, NSTC applied a USGS geospatial model of remoteness using the Colorado Plateau habitat fragmentation data. We assume that areas furthest from developments (e.g., roads) are least disturbed by human activity. The intent of this exercise was to determine if this model could facilitate regional land use planning.

In this context, a "remote area" is an area *relatively* free from human disturbance as measured by the time it takes to access the area on the ground. The "remoteness model" uses slope, land cover type, and road proximity as the primary variables. A travel time penalty is applied for changes in these conditions. By assessing differences in the primary variables, the model determines the easiest travel route and travel time threshold to every point on the landscape. This effort provided information on the impact of roads within a selected area of the Plateau in greater detail than our original datasets permitted. For this reason, this portion of the project differs from the strategy employed in the previous two examples.

Human activity on the landscape has numerous ecological effects. Land managers will find it useful to identify remote areas, or areas that are difficult for humans to access, because they may exhibit less ecological disturbance. Many land use activities can potentially decrease the remoteness of an area, such as oil and gas development, road construction, recreational activities, and urban development. We assume that remote areas are least likely to be disturbed by human activity. Such areas thereby retain pristine value and suitability as habitat for species sensitive to human impact. Remote areas are also less impacted by fragmentation and the negative effects of roads discussed in previous sections. Quantifying remoteness can provide important information on the ease or difficulty of human access and the time it takes to reach a point on the landscape (Figure 9). Maintenance of remoteness can be a useful strategy for management of ecological resources in targeted areas.

Scale

The target area for remoteness modeling is the Uinta-Basin Floor, one of eight Level IV ecoregions within the Colorado Plateau Level III ecoregion. The Uinta Basin, located in northeast Utah and northwest Colorado, was selected as our case study due to its relative degree of fragmentation and its role as critical year-round mule deer habitat.

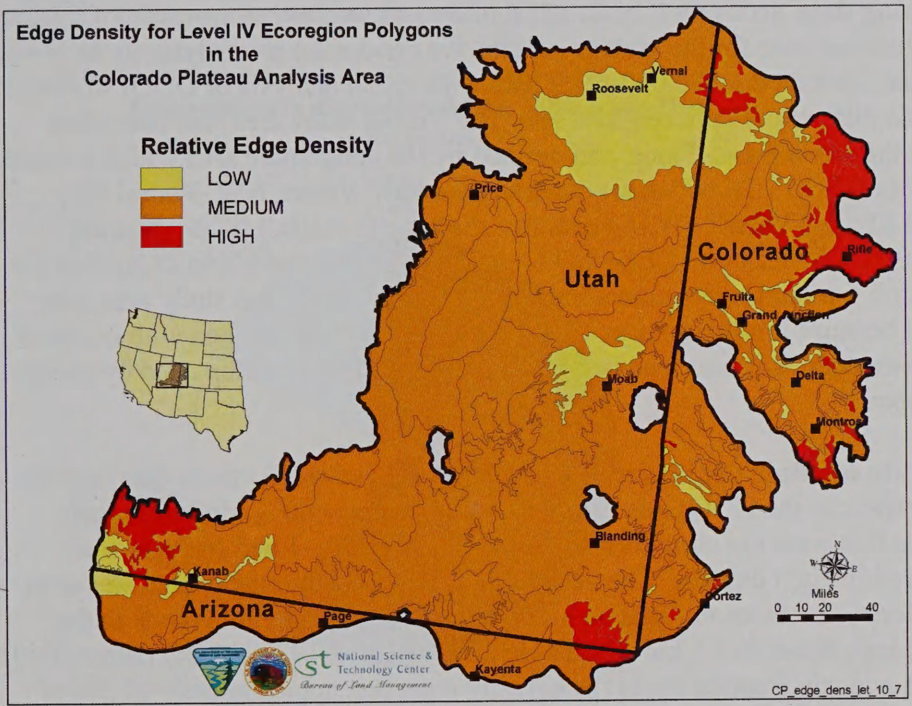


Figure 9. Edge density ranking

Data

Selecting data to use to build the remoteness model was a challenge. The U.S. Geological Survey DOQs contained the most current depiction of the features on the ground. However, vector road data is a key component for fragmentation analysis and remoteness modeling. We ultimately used USGS GDT and USGS DLGs compiled from 1:100,000-scale maps to construct a model to examine remoteness.[5] The remoteness model is based on analysis of terrain slope, land cover type, and road surface. National Elevation Dataset, 30m resolution, was used as input to model upslope and downslope time in minutes per meter. Road data was selected for the study area, classified according to surface material, and converted from vector to raster data for input to the remoteness model. We estimated access times for the Uinta-Basin ecoregion with travel beginning on any

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[5] Development of this dataset was previously described in the "Data Quality and Vintage" section of Landscape Fragmentation.

paved road at zero travel time. We estimated speed on dirt roads as a uniform 30 mph and assumed off-road travel to be on foot at a speed of 2 mph on flat bare ground or grassland. We applied speed penalties for slope and for other land cover types. Sagebrush flats dominate this ecoregion with cultivated and uncultivated grasslands on the valley floor, and forests at higher elevations and in stream valleys. Topography is generally flat valley with occasional scarps and incised canyons surrounded by piedmont hogbacks and mesas.

Assessing data accuracy: In an effort to determine the true accuracy of DLGs and to compensate for the vintage of data, we conducted an analysis in the Vernal area that combined 1:100,000-scale data with visual analysis of DOQs to detect possible differences between data sets. The Vernal study area was identified within the Uinta Basin-Floor, and defined by the geographic area which coincides with four USGS 1:24,000-scale quadrangle maps: Vernal NW, Vernal NE, Vernal SE, and Vernal SW. To examine distance to roads, USGS obtained 1:100,00 DLG, 1:24,000 DLG, GDT, and Utah AGRC roads and DOQ data for the four 7.5-minute maps coinciding with Vernal, Utah. This study area was chosen because it represents an urban-wildland interface, an area with complex land ownership, an area impacted by recreation and an area impacted by energy development.

Integrate multiple data layers: USGS analysts evaluated vector data content with respect to the DOQs and collected approximately 60% additional road features that were not contained in the existing dataset. Road features were portrayed in eight classes. The new roads data was converted from a vector to raster form. Distance to roads analysis reveals that USGS DLG roads in the Vernal area detect 883.1 km whereas hand analysis of 1997 DOQQ detect 2079.6 km. Previously mapped roads (DLG) only represent approximately 42.5% of roads on the landscape because the data is older and the cartographic standards under which it was collected varied. This denotes a change in road density based on data availability and collection methodology. The overrepresentation of roads from aerial photography is also a potential issue. For example, earthquake fault lines or fence lines can appear as a road in photography. Road data collected from DOQs needs to be verified by field analysis. Until that time, extrapolation of results for the Vernal and Uinta Basin-Floor study areas may not be appropriate for the entire Colorado Plateau due to differing conditions throughout the area. We recommend additional study areas be identified and the above methods be used for a more comprehensive landscape analysis.

Results and Discussion

The remoteness model can be used to assess the impact of roads on mule deer habitat. The model generates the number of acres that are remote within BLM land, private, USFS to determine the easiest travel route and travel threshold to areas most remote. Greater than 80% of the landscape is accessible within one-hour travel time (Figure 10). Only 1% of the Uinta Basin requires travel time greater than four hours to access. Modeling remoteness is a valuable tool for determining areas for management opportunity, and can be coded for alternative forms of transportation: horseback, mountain bike, motorcycle or all-terrain vehicles. Remoteness modeling makes a variety of derivative studies possible: GPS based radio collars on animals can test whether species prefer habitat that is isolated from human influence; detailed maps of habitat can be evaluated in terms of fragmentation associated with ease of human access; assessing the correlation between access, road density and land use; predicting how remoteness may change if road densities increase from oil and gas development.

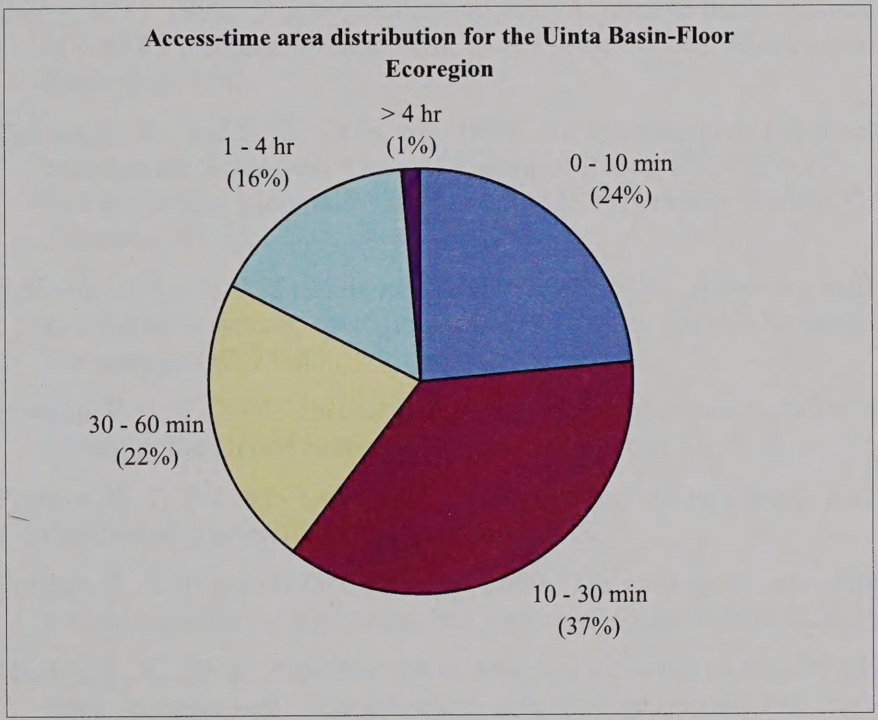

Figure 10. Access time requirements for Uinta Basin-Floor

The Uinta Basin-Floor has 3,221 abandoned and 3,185 producing oil and gas wells according to year 2000 data. The potential for further development in the Basin suggests road densities may increase. Greater road densities will directly increase fragmentation while reducing the remoteness character of the Basin. The success of this exercise in facilitating land use planning is unproven. However, Price and Vernal Field Office managers and resource specialists expressed interest in the remoteness and habitat analysis. Further customization of the analyses is possible to address more specific information needs.

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APPENDIX A - INVENTORY OF EXISTING DATA

The Colorado Plateau Data Coordination Committee has engaged in compiling a Resource Atlas for the Colorado Plateau (http://www.landuse.com/coplat/overview/Opening01.htm). The information below is intended to supplement the data sources available in the Resource Atlas.

Data		Source	Location	Metadata	Type	Content
Automated Geographic Reference Center		AGRC-Utah	http://agrc.its.state.ut.us/	available	various downloadable data	Climate, utilities, wildlife, land status, natural resources
Changes in Species Composition		USFS	http://www.rms.nau.edu/publications/rm_gtr_295/		text, images, links	Ecological change
Effects of Recreation on Rocky Mountain Wildlife		Montana Chapter of The Wildlife Society	http://www.montanatws.org/pages/page4b.html		searchable database	Bibliographic information on the effects of recreation on wildlife
Geocommunicator		BLM/USFS	http://www.geocommunicator.gov/	available	downloads	Geographic data
Grey/ White Literature Review		CP Science Committee				Ongoing regional literature search
Land Survey Information		BLM	http://www.geocommunicator.gov/lsi/	available	geographic and cartographic data downloads	Geographic information from the BLM Geographic Coordinate Data Base (GCDB) representing the Public Land Survey System (PLSS) of the United States
Land Use History of Colorado Plateau		NAU	http://www.cpluhna.nau.edu/		text, images, links	Changes in land cover and land use spcific to the Colorado Plateau
Land Use History of North America		USGS	http://biology.usgs.gov/luhna/index.html		text, images, links	Changes in land cover and land use
National Exosure Laboratory -		EPA	http://www.epa.gov/nerlesd1/land-sci/projects.htm		various data sources	Landscape change

Landscape Ecology Branch						
Natural Diversity Info System		CDOW	http://ndis.nrel.colostate.edu/	available	various downloadable data	Species, land use and conservation planning
NAU Land Treatment Project		CP CESU				Ongoing regional review of BLM historical land treatment data
Southern Rockies Ecoregion Project		CU	http://csf.colorado.edu/srep/		text, images, links	Resource assessment
Southern Utah Fuels Demonstration Project		Rocky Mountain Research Station			draft paper	Joint Fire Science Program funded project on fuels modeling and mapping
Southwest Data Center			http://www.landuse.com/coplat/overview/Opening01.htm		text, images, links	Land use
Southwest Plant Mapping		USGS	http://wapiti.wr.usgs.gov/swepic/			plants
Southwest Strategy		Federal, NM, AZ, tribal	http://www.swstrategy.org/		text, images, links	A joint community and conservation management effort working with public to restore cultural, economic, environmental characters of the region
Statewide Geographic Information Database		SGID-Utah	http://agrc.utah.gov/sgid.html	available	various downloadable data	Land use, quad maps, climate, utilities, wildlife, land status, natural resources
Sustainable Minerals Roundtable		Mackay School of Mines, UNLV-Reno	http://www.mackay.unr.edu/smr/			Minerals indicators
UT Conservation Data Center - Interactive Maps		Division of Wildlife Resources, UT	http://utstdp-ims.state.ut.us/wildlife/viewer.htm	available	interactive maps	wildlife data

Vegetative research plots for Colorado Plateau		USGS Rocky Mountain Research Center				Vegetative plots for Grand Staircase Escalante National Monument, Rocky Mountain National Park, other parts of Colorado Plateau
Western Slope User Group		City, County, State, Federal	http://www.co.mesa.co.us/imd/gis/users.htm		text, images, links	To provide a gateway for western slope GIS users to share knowledge and data
White Paper - Establishing Reference Sites		CP Science Committee			draft paper	Draft process for establishing research reference sites
Wildlands Roads Inventory		Wildlands Center for Preventing Roads	http://www.wildlandscpr.org/databases/index.html		searchable database	Bibliographic information on roads

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APPENDIX B - REGIONAL DATASET

Landscape Analysis

- Omernik's Level III Ecoregions, a spatial layer defining 52 ecological units in conterminous United States and the boundary of Colorado Plateau.
- Ecoregions of Utah, a spatial layer defining Level IV Ecoregions in the Utah portion of the Colorado Plateau.
- Ecoregions of Colorado, a draft spatial layer defining Level IV Ecoregions in the Colorado portion of the Colorado Plateau.
- Soils, precipitation, cover types, ecoregion, and elevation to estimate the Level IV boundaries for northern Arizona.
- National Land Cover Data, a spatial layer of a 21-class land cover classification scheme available by state (http://landcover.usgs.gov/nationallandcover.html).
- National GAP Analysis Land Cover, a spatial layer that portrays the extent and distribution of existing vegetation (http://www.gap.uidaho.edu/searchpages/LandCoverSearch.asp).
- SAGEMAP, multiple spatial layers important for our understanding and management of shrub–steppe lands and associated communities (http://sagemap.wr.usgs.gov/).
- TIGER2000, a spatial layer of infrastructure elements including roads and trails at the 1:100K scale. Topologically Integrated Geographic Encoding and Referencing system, available by state (http://www.census.gov/geo/www/tiger/).
- GDT roads, a spatial layer component of USGS National Atlas that portrays major roadways in the United States. Available by state.
- USGS 1:100K road data, a spatial layer component of USGS National Atlas that portrays roads and trails composed of USGS digital line graphs available by USGS quadrangle maps.
- Utah oil and gas well data, a spatial layer of well type, status, and location (ftp://ftp.blm.gov/pub/utah/minerals/).
- Colorado oil and gas well data, a spatial layer of well type, status, and location (http://oil-gas.state.co.us/).
- Land status, jurisdiction, and BLM administrative boundaries—a variety of spatial layers depicting administrative boundaries for surface ownership in the Western States. Available through BLM.

Mule Deer Habitat Analysis

- Omernik's Level III Ecoregions
- Colorado data, a spatial data layer portraying mule deer habitat types. Available through the Colorado Division of Wildlife.
- Utah habitat data, a spatial layer portraying coarse mule deer habitat types. (http://www.utahcdc.usu.edu/ucdc/DownloadGIS/disclaim.htm)
- Road dataset created for the landscape fragmentation analysis
- Utah oil and gas well data (ftp://ftp.blm.gov/pub/utah/minerals/).
- Colorado oil and gas well data (http://oil-gas.state.co.us/).

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APPENDIX C - REGIONAL DATA NEEDS

The following is a list of resource inventory data needs identified by resource specialists on the Colorado Plateau. NSTC has identified the needs addressed in this regional resource assessment.

Oil& Gas

- How many wells? **Completed**
- General locations of fields. **Completed**
- Production information on daily, yearly and cumulative bases. **Not available regionally**
- Pipeline locations and miles of line. **Utah data available on http://sagemap.wr.usgs.gov/**
- Economic impact – to jobs and tax base. **Not addressed**
- How much of BLM land is leased/developed/abandoned? **Completed**

Wildlife

- How many acres of critical habitat by species occur in the region? **Mule deer completed**
- Locations of habitat by species. **Mule deer completed**
- Major migration corridors. **Not available regionally (CO data available through NSTC)**
- How many commercial game species? **Not addressed**
- Economic impact and value of wildlife species or consumptive use of species. **Not addressed**

Vegetation

- How many acres and where are major vegetation communities within the region? **Completed**
- How many acres and where are the invasive communities? **Not available regionally**
- Where have conversion projects occurred? Acres by veg type.
- What is the Region's fire history? **Completed**

Recreation

- How many CRP's on the Plateau? **Not addressed**
- What types of uses by CRP holders? **Not addressed**
- Major recreation use areas by type. **Not addressed**
- How many acres of WSAs and 202s and where are they located? **WSA's available**
- Economic impacts of recreation to jobs and tax base. **Not addressed**

Water

- How many acres of degraded streams and their locations? **Not addressed**
- How many miles of riparian habitat and their locations? **Completed**
- Condition classes of riparian. **Not addressed**
-

Grazing

- How many allotments in use, described? **Not addressed**
- How much use by livestock by habitat type? By season. **Not addressed**
- What areas have had health assessments? **Not addressed**
- What are the economic impacts to jobs and tax base? **Not addressed**

Socio-economics

- Current population information. **Not addressed**
- Existing job sectors. **Not addressed**
- Current tax base. **Not addressed**
- Land ownership by acres. **Completed**

Soils

- Areas in acres of sensitive soils. **Not addressed**
- Where are and how many acres of salinity areas? **Not addressed**

Cultural Resources

- What are the locations of Native American tribes? **Not addressed**
- What are the artifact site densities and locations? **Not addressed**

APPENDIX D - INFORMATION SYNTHESIS STRATEGY

In 2002, the National Science and Technology Center (NSTC) staff designed and tested a strategy for synthesizing available regional data from various agencies and sources and converting the regional information into a format useful to public land managers. After review of many regional assessment techniques and field-testing a strategy, the NSTC recommends the following four-step information synthesis strategy:

Step one: Interested managers identify a regional issue of shared concern. With subject matter assistance, they:
- clearly and concisely articulate the problem;
- decide which questions, if answered, will contribute substantially to resolving a regional problem; and
- agree on the regional resource assessment goal and objectives.

Step two: Subject-matter experts identify required data and the appropriate geospatial scale to characterize these data. They:
- establish data requirements criterion: consider social, economic, and biological information;
- delineate assessment boundaries based on the management issue, agency need, biogeophysical and socio-economic attributes of the area;
- determine temporal/ spatial domain and scale of analysis; and
- identify and investigate potential data sources.

Step three: Staff collect and process relevant data. The project lead:
- establishes processing standard operating procedures;
- collates and as appropriate using subject-matter experts, analyzes data; and
- documents findings in a spatial context and in a written report.

Step four: The project lead is responsible for determining if the goals and objectives of the resource information synthesis were met. S/he:
- obtains managers' feedback;
- monitors product use; and
- reports findings.

Although this strategy is designed to be accomplished in six months, significant effort is required to complete each of the strategy's four steps. If sufficient resources cannot be committed to the effort during the six months, the process will take more time. Management's input is essential for steps one and four and advised for steps two and three.

STEP ONE: Select an Appropriate Management Issue

It is important to have clear direction on what type of regional resource information to collect. The quantity of data potentially available for a region can be overwhelming unless specific issues are identified. Not all issues are appropriate for regional analysis. Management issues that are dependent on understanding patterns of ecosystem health, integrity, and land use are best suited for regional analysis. Site specific, local, and policy driven management issues are unlikely to benefit greatly from a regional resource assessment.

To facilitate selection of management issues that are likely to be appropriate for a regional information synthesis and analysis investment, we recommend sequential completion of the following tasks:

1. **Identify an appropriate target area**
   Selection of a relatively homogeneous area is of critical importance for several reasons: managers are likely to have common goals, interests and needs; managers are more likely to have established relationships; information is often derived and organized regionally; and opportunities for solution partnerships are abundant. Ecoregion boundaries are best suited to providing context for broad-scale analysis of terrestrial ecosystems.

2. **Invite managers to participate in a regional information synthesis process**
   A regional understanding of management issues and potential solutions is possible if the major land managers in the region are interested and available to share their perspectives face-to-face. A group of interagency land managers interested in the regional perspective will probably generate the most realistic resource management opportunities by the end of the resource assessment process.

3. **Review Resource Management Plans (RMPs)**
   Once the managers are identified, request the most recent documented source of land and resource management needs information for land management units in the region of interest. Search each document and record in tabular format the primary management issues expressed for each management unit.

4. **Prioritize resource management issues for the individual**
   Provide the managers with the primary management issues results derived from RMPs. Survey the managers to determine regional management priorities. The survey should be brief and clear, asking managers to identify the priority management issues in their jurisdiction. An example survey and responses can be found in Appendix E. Synthesize responses into a list of resource management issues similar to the example in Appendix F. Information gathered from RMPs in task 3 is useful in synthesizing the responses and in identifying commonalities. The final result should be a list of broad-scale issues and possible questions of importance to managers across the region.

5. **Prioritize resource management issues for the region**
   Meet directly with managers in the region to determine if issues identified in the previous task are understood and appropriate for a regional resource assessment. Select top priority regional resource management issues. This meeting should

include planners, subject matter specialists, regional science coordinators, and headquarters staff familiar with the region of interest.

6. **Identify resource assessment goals and objectives**
   At the same meeting (task 5 above), identify the information needed to resolve the highest priority regional resource management issue. It is often helpful to frame the needs as questions:

   - Which resources are associated with the issue and why?
   - What's happening to those resources and why?
   - Are there opportunities to resolve resource management conflicts?
   - What are the potential consequences associated with each opportunity?

   Document agreed upon project goals, measurable objectives, associated questions, and, as appropriate, desired results and products.

STEP TWO: Identify Data Requirements & Appropriate Geospatial Scale
Interdisciplinary subject matter expertise is required to complete Step 2.

Identifying scale is necessary to provide a context for describing and analyzing resource condition. A variety of approaches exist to classify ecosystems and rank them by spatial scale (see Dahms and Geils 1997). Choosing the appropriate scale for landscape analysis depends on the organism or issue of concern. For example, the extent of the scale for examining a particular butterfly species may be smaller than the scale for examining bald eagle migratory patterns. Some of the most important aspects of biological diversity and environmental change occur over entire landscapes (Riitters, et al. 1995). Therefore, one of the best uses of ecosystem classification is to stratify landscapes into smaller units with similar resource conditions, components, and processes to provide a context for understanding change (Dahms and Geils 1997).

1. **Convene a group of subject matter experts**
   A group of appropriate subject-matter experts should be brought together to discuss and agree to actual data needs to meet project goals, objectives, and desired outcomes. The selection of appropriate experts depends on the management issue being investigated.

2. **Identify critical regional resource assessment data**
   The subject matter experts are responsible for advising the project lead on data requirements criterion. Social, economic, and biological resource indicators should be considered since they are usually critical for the discovery of management opportunities.

3. **Delineate an appropriate science-based resource assessment area**
   Concurrently with the identification of critical data needed, the subject matter experts should delineate the science-based resource assessment boundary likely to contribute results relevant to the goals, objectives and questions posed.

4. **Determine temporal/ spatial domain and scale of analysis**
   Subject-matter experts, familiar with the information and data collected, should determine the scale of analysis relevant to the issues. The most valuable information to managers is that which best addresses the management issue of interest at the "right" scale.

5. **Delineate the resource assessment boundary and justify**
   The project lead needs to select and justify the project boundary by overlaying the political area of interest identified by managers in Step 1 with the science-based boundary identified by subject-matter experts. His/her decision should be peer-reviewed. Reasons to support this decision should be documented and reported to the regional manager's group.

STEP THREE: Collect and Process Relevant Data

Federal and state agencies, counties and municipalities, universities and private organizations can all provide valuable information and data on the region of interest. A group of interagency and intergovernmental resource managers and scientists, academics, and environmentally focused private organizations interested in the regional perspective will probably generate the largest amount of information and realistic regional resource management opportunities. If this is not the situation, the data source identification, collection, integration, and analysis processing time could be extensive.

Existing regional data can limit the scale of analysis. The selected scale may be ecoregions, river basins, watersheds, or socio-economic units, though resource information may not be available for these geographic designations (Dahms and Geils 1997). Further, while aggregating spatial data from fine scales to coarse scales is a well-documented practice, converting coarse data to fine is not as successful (Schmidt et al., 2002). The data collected should always be relevant to the scale of analysis that is why scale is determined first.

Data collected is very likely to have compatibility problems. Partnerships can greatly expedite data conversion.

1. **Establish a data search and processing team**
   It takes a small team (with at least one member well versed in GIS) devoted to the data sourcing, collection, access, and synthesis process to meet basic regional resource information inventory goals.

2. **Create a work plan with appropriate milestones**
   The project lead is responsible for seeing that the project stays on task and meets the project on time and within budget. If they cannot do this because of unforeseen obstacles, they need to keep the regional managers group informed. A project work plan and standardized operating procedures are recommended to prevent project drift and unnecessary work.

Plan for continuous tracking and documenting of data sources. New information is constantly being generated.

3. **Collate and analyze required data and create required products**
   The analysis team should begin by assessing data quality and vintage. As data layers are integrated, the team may need to manipulate certain data – especially spatial data – to conform to the temporal and spatial scale of analysis. Conduct the analysis according to an established framework. Subject matter experts should be consulted as appropriate when making an assessment of data quality and when interpreting and incorporating analysis results in a written report.

4. **Prepare interim report and distribute**
   The interim report should include the following:
   - A summary of products provided as a result of the resource assessment;
   - A summary of basic quantitative findings and information deficits;
   - A demonstration and explanation of how each objective was or was not met;
   - Recommendations on how managers, planners and resource specialists can potentially use and build upon the resource assessment;
   - An annotated bibliography of sources used in for the information synthesis; and
   - A database of information used in the synthesis, including source information, data access requirements, and describe the metadata and disposition of raw data.

   Upon delivering the report, ask managers if the results were as expected and if not, "why not?" Ask the managers if they think they will use the results and how they might apply the regional information they now have. Document their initial reactions to compare with information collected in Step 4 below.

STEP FOUR: Short-term - Get feedback from managers; Long-term – Measure success

The intent of Step 4 is to provide a forum for learning whether the regional information synthesis effort was successful (useful) and to determine where and how process and product modifications should be made for further investigations.

1. **Solicit feedback as appropriate**
   At any time during Steps 2 and 3, test assumptions and the utility of draft products through peer review, informal presentations, and discussion. Continually question if the level of data interpretation is of value to managers. Feedback from managers will provide insight on how the process can be amended for greater utility. If the managers desire further information syntheses or analyses, implement warranted process changes if possible while remaining on task and within budget.

2 **Plan to measure success**

The true test of a successful information synthesis project is if managers use the results. Johnson et al. (1999) recommend asking three questions to determine information synthesis effectiveness:

- Was the assessment focused – did the assessment lead to solution of the problem that caused it to take place?
- Was the assessment contextual – did it significantly improve understanding in the bioregion?
- Was the assessment integrated – were the results considered in management analysis and actions?

After one year, survey the regional managers group and select subordinate resource management staff. Ask them the three questions listed above. It may be helpful to plan for this feedback process in advance by providing the managers with a template for feedback in the interim report provided at the conclusion of Step 3.

3. **Create the final report**

The final report should include: a concise presentation of management issues; the original resource assessment goal and objectives and a discussion of whether the objectives were met; a discussion of resource distribution and use patterns observed; identified data gaps; and unanswered questions and project shortcomings; and lessons learned and recommended process changes, if warranted.

If the managers desire additional information synthesis and or analyses, capture the expectations in measurable objective statements and recommend means of meeting perceived needs.

APPENDIX E - MANAGERS' INTEREST SURVEY & RESPONSES

Managers were asked to identify as many as 5 priority resource issues facing land managers in the Colorado Plateau region; issues they thought would benefit from regional information synthesis and interdisciplinary analysis. Managers were asked to identify:

- **What values or conditions make the issue a concern?**
- **What information is needed to address the issue?**

Below are the responses from managers on the Colorado Plateau. The issues are not ranked in order of importance.

1. Forest sustainability—Woodcutting, for both personal and commercial use, is a popular activity on the Colorado Plateau portion of Kingman Field Office. Although a limited supply of wood is available, suitable locations for woodcutting are limited because of access and cultural or historical resource concerns. Sustainability of this resource is also of concern because only a small portion of the field office contains pinyon–juniper (PJ) woodlands.
    a. Can we continue to meet the demand for woodcutting in this area?
    b. GIS overlays of suitable stands of pinyon–juniper, access routes, and cultural resources are needed for future planning.
    c. What is the sustainability of this resource?

2. Dispersed recreation activity and effects to soils, cultural sites, and special status species (fragmentation). Particular concern about OHV use.

3. Pinyon–juniper woodland treatments. Loss of important habitat from historical chaining, present hazardous fuel treatments and changes caused by wildfire, insects, and disease in PJ habitat in the Northern Colorado Plateau.
    a. Landscape-level effects on species that rely on mature stands of PJ
    b. Watershed conditions related to mature stands of PJ throughout Colorado Plateau.

4. Recreation–tourism expansion—Kingman Field office working on an EIS for improvements to Diamond Bar Road, the access route to Grand Canyon West on the Hualapai Reservation. If this road is paved, we anticipate that additional developments will be built at Grand Canyon West, and tourism to this area will increase. This will probably increase recreational use along Diamond Bar Road, which passes through an ACEC.
    a. What management is needed to address future recreational use in this area?

5. Habitat fragmentation: best management practices for species and population conservation. A particularly relevant issue is raptor management in the oil patch.

6. Increased recreation demands on public lands and changes in types of recreational use.
    a. Limits of acceptable change and socio-economic analysis of changing demographics on the Colorado Plateau.

7. Prescribed burning—Kingman Field office has an active prescribed burning program. We have identified prescribed fire as a potential tool in the Colorado Plateau portion of our field office.
    a. Prescribed burning could be used to reduce pinyon–juniper encroachment, improve wildlife habitat, and improve rangeland condition.
    b. Information needs to include an inventory of this vegetation type; soils information (erosion potential).
    c. Interagency coordination with Hualapai Tribe and NPS would also be needed.

8. Cultural resource protection

9. Sage brush treatments. BLM and others have been treating sagebrush stands with greater than 15% canopy cover to reduce sage brush dominance and improve ground cover and reduce erosion across the Colorado Plateau.
    a. What are the critical levels of sage brush needed for various sage brush obligate species throughout their lifecycles?
    b. What are optimum densities in various sage brush communities to enhance the habitat needs of species such as the Gunnison Sage Grouse?

10. Conversion of native habitats to non-native from invasive species and fire effects.

11. Rural community economic sustainability

APPENDIX F - RESOURCE MANAGEMENT ISSUES

Regional Issues are unresolved conflicts concerning alternative uses of resources and their conditions. Regional issues occur at the intersection of program areas and occur throughout the demonstration area. Issues should be accompanied by key questions regarding what should be reviewed.

- What are the present resource conditions and levels of resource use?
- What is the present trend in resource condition?
- What are the implications of changing those trends for maintaining or improving resource conditions?
- What BLM management opportunities exist to address resource issues and conditions?

1. Energy and Minerals—Can BLM meet increasing demand for energy development while addressing potentially adverse consequences?
Demand for energy production in the region is increasing. Production of energy (oil and gas, coal), locatable minerals, and non-energy-related leases are important economic values. However, increases in demand for leases, changes in level of production, and changes in commodity type can affect the resource condition in the region.

- In what form and where does energy development presently occur?
- What is the present trend in resource condition?
- What are the implications of changing those trends for maintaining or improving resource conditions?
- What are the regional RFD scenarios according to available information?

2. Cultural Resources—Can BLM reduce degradation and loss to cultural values while meeting public demands for use of those resources?
Many culturally significant resources (natural and human made) occur throughout the region. These resources are important to both American Indian Tribes and the public at large. Value and use of these resources may be affected or restricted by actions on the ground.

- What cultural resources exist in the region? Where do they exist and what is their present condition?
- What is the present trend in resource condition?
- What are the implications of changing those trends for maintaining or improving resource conditions?
- What opportunities and range of uses (versus protection from degradation) exist?

3. Recreation—Can BLM respond to increasing demand for a wider variety of recreational opportunities by an increasing number of visitors, while maintaining related resource values?

The region hosts a range of recreational opportunities including visual resources. Population growth in the region has led to increasing demand for recreational opportunities.

- What range of activities occurs in the region?
- What is the present trend in resource condition?
- What are the implications of changing those trends for maintaining or improving resource conditions?
- What are the mitigation and restoration possibilities for managing recreational uses and conflicts?

4. **Special Area Designation**—Should BLM designate and manage special areas in the region?
As populations in the region expand, development encroaches on previously undeveloped areas adjacent to, and within, Public Lands. Designating special areas (such as wilderness, Wild and Scenic Rivers, research natural areas, and ACECs) creates opportunities for managing resource use conflicts.

- What is the degree of ecosystem integrity and connectivity across the region?
- What is the present trend in resource condition?
- What are the implications of changing those trends for maintaining or improving resource conditions?
- What are the opportunities for managing the cumulative effects on special areas?

5. **Fire**—Can BLM manage fire regimes as a tool to achieve resource management objectives?
Fire regimes in the region have been altered by human activity resulting in changes to the composition and structure of vegetative communities, such as increases in fuel load, exotic annual grasses, conifers, and woody species; and increases or decreases in herbaceous species. Further, expanding human populations, development, and infrastructure increase an agency's fire-protection costs.

- What is the present condition of fire regimes?
- What is the present trend in resource condition?
- What are the implications of changing those trends for maintaining or improving resource conditions?
- What opportunities exist to comply with National Fire Plan and manage the cumulative effects of altering the role of fire in the region?

6. **Vegetation and Habitat Management**—What are the desired plant communities and conditions, and what are the best management practices to achieve those conditions?
Vegetative community composition and structure is changing due to a variety of forces including the expansion of wildland–urban interface, fragmentation, human use, colonization by invasive species, reductions in patch size, changing fire regimes, and availability of resources among others.

- What is the present condition of native communities and invasive species?
- What is the present trend in resource condition?
- What are the implications of changing those trends in plant community structure, composition, and function?
- What restoration efforts can help minimize these changes or direct recovery toward desired conditions?

7. Maintaining Land Health and Resource Base—Can BLM maintain ecosystem integrity and sustain human use? Changes to community structure and composition have affected ecosystem functions. Expansion of human development and exotic species has impaired ecosystem function, reduced historical range of sensitive species, and degraded resource condition. Achieving the desired conditions for the resource issues cited above requires established standards to measure progress.

- What is the present functional condition of ecosystems, watersheds, and plant communities?
- What is the present trend in ecosystem function?
- What are the implications of changing those trends for maintaining or improving healthy ecosystem function?
- How can the region meet established functional conditions and manage conflicting uses and emphasize complimentary use

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APPENDIX G - COLORADO PLATEAU MANAGERS MEETING

Comments from October 17, 2002 Meeting

1. There was great value in the overall learning process of defining what issues are appropriate for regional analysis and testing the application of regional data.

2. This presentation exemplifies the difficulty in working with regional datasets. It may be more practical to redefine the questions. Managers need to tell NSTC what their needs are. NSTC can make regional maps and compile databases (act as a clearinghouse), but how does regional data really apply locally? Regional data and information is not applicable at finer scales, even if it addresses cumulative effects. If a finer scale is used, results will vary; for example, fragmentation increases at finer scales.

3. The Colorado Plateau Managers Group operates as a regional management group. If regional data for use in regional planning are not what the group desires, then the group should consider redefining its information needs.

4. Consider working with planners to develop management prescriptions and thresholds of change. This effort identifies the need to have threshold data when applying regional information to local level.

5. Is this an iterative process or a management tool? What issues are actually appropriate for regional interests? What are the criteria for establishing questions for analysis? How can this information address issues at multiple scales?

6. The process described is proactive. It provides an important tool for screening for priority management areas, but what are the appropriate questions to ask? The scale of the examination was too large to be applicable at local levels, and the utility of regional data is questionable. Perhaps more specific usage is appropriate.

7. A regional synthesis is a useful approach for defining research needs, specifically the effects of roads on various habitat types.

8. The project has relevance to Resource Management Plans that address mule deer.

9. The Vernal Field Office (Utah) staff acknowledges the utility of the synthesis and would like to work with NSTC staff to further examine smaller areas (110,000 acres). It was unsettling for managers in Vernal to see the reduction of mule deer habitat. They have additional information that would be useful in establishing a more complete picture of mule deer habitat in the area. These

data help validate why new roads should not be built for oil and gas development.

10. Why were the most current databases not used instead of the most complete databases? (i.e., why did NSTC choose to use complete 1:100,000-scale road coverage from 1980 rather than a mixture of 1980 100K and more recent 1:24,000-scale maps, where available?) It seems that the most recent picture would be more practical.

11. It is necessary to have level of use, closure information, and season of use for road datasets to create a complete inventory of roads data. How useful are the data presented here without such supplementary information?

12. Information should be more specific to apply it to the identified target areas. How well does this project marry with analyses of other issues?

13. Many OHV, transportation, ATV, and mountain bike use areas don't show up at the regional scale. What utility does this information have for managing these activities at the Field Office level?

14. It would be beneficial to have all data available even if they are not recent. Simply advise us "user beware." Let managers have access to and use the data at their discretion. This process has shown the limits of the application of regional data. It would be helpful to have all data in a common database, with NSTC as a focal point. The database might include grazing information, fire, fire management planning, and the most recent data for a region.

15. Regional air quality data would be useful. Power line installation and the National Energy Plan are good candidates for regional analyses. BLM could help drive some issues rather than accepting what is given to them without any input.

16. Will the Colorado Plateau Science Committee work with NSTC to examine regional issues and crystallize science questions? Other organizations are working at this scale, and BLM should as well.

17. Washington Office will not fund the next phase(s) unless there is consent from the managers group that the regional data approach is worthwhile.

APPENDIX H - ECOREGION DESCRIPTIONS

Level III Ecoregion[6]

The Colorado Plateaus: is comprised of uplifted, eroded, and deeply dissected tableland topography and precipitous side-walls that mark abrupt changes in local relief, often from 300 to 600 meters. Its benches, mesas, buttes, salt valley cliffs, and canyons are formed in and underlain by thick layers of sedimentary rock. Extensive pinyon-juniper woodland dominates higher elevations and saltbush (*Atriplex* sp.) greasewood (*Sarcobatus* sp.) and blackbrush (*Coleogyne ramosissima* Torr.) communities are common at lower elevations. Summer moisture from thunderstorms supports warm season grasses and many endemic plants, and species diversity is great. Several national parks are located in the ecoregion and attract many visitors to view their arches, spires, and canyons. Major gas and oil fields are found in the Uinta Basin portion of the Semiarid Benchlands and Canyonlands, Uinta Basin Floor, and North Uinta Basin Slopes Level IV ecoregions.

Level IV Ecoregions

Monticello Upland: Gently sloping and blanketed by eolian material deposited in the lee of the Abajo Mountains. It receives more precipitation in a typical year than the surrounding portions of the surrounding Semiarid Benchlands and Canyonlands ecoregion. Deep, silty Mollisols are characteristic and are able to retain enough available moisture to naturally support Wyoming big sagebrush (*Artemisia tridentata* Nutt. ssp. wyomingensis) and associated grasses. These soils now sustain dryland farming for winter wheat and pinto beans. This is the only extensive dryland farming area in the Utah portion of the Colorado Plateaus. Shallow or stony soils occur along the rims of benches and minor escarpments and support pinyon-juniper woodland.

Shale Deserts: This arid ecoregion consists of nearly level benches, low rounded hills, and badlands. It is sparsely vegetated with mat saltbush, bud sagebrush (*Picrothamnus* Nutt.), galleta (*Pleuraphis* sp.), and desert trumpet (*Erioginum inflatum* Torr & Frem) . Soils are mostly Entisols and Aridisols; they are mostly shallow and clayey and contain salts and gypsum. Clayey soils swell when moist and are slowly permeable. Surface runoff and resultant erosion occurs during and after rainstorms. Scattered, gravel-capped benches occur and protrude from the present denudational surface because they are much more resistant to erosion than the surrounding shales. Deep, vertical-walled arroyos are carved where surface water concentrates. These arroyos are major contributor of sediment and salt to the Colorado River. Floodplains have alkaline soils that support greasewood, alkali sacaton (*Sporobolus airoides* (Torr.) Torr.), seepweed (*Suaeda* sp.), and shadscale (*Atriplex confertifolia* (Torr. & Frém.) S. Wats.).

Semiarid Benchlands and Canyonlands: Characterized by broad grass-, shrub-, and woodland-covered benches and mesas. Elevations mostly range from 5,000 to 7,500 feet

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[6] Woods, A.J., D.A. Lammers, S.a. Bryce, J.M. Omernik, R.L. Denton, M. Doneier, and J.A. Comstock. 2001. Ecoregions of Utah (color poster with map, descriptive text, summary tables, and photographs): Reston, Virginia, USGS (Map scale 1:1,175,000).

and are higher than those of the Arid Canyonlands. Low escarpments separate remnant mesa tops and narrow canyons from surrounding benches. Bedrock exposures (i.e., slickrock and fins) are common along rims, escarpments, and on step dip slopes. Soils are mostly Entisols. These deep eolian soils are composed of fine sand and support warm season grasses, winterfat (*Krascheninnikovia lanata* (Pursh)), Mormon tea (*Ephedra viridis* Coville), four-wing saltbush (*Atriplex canescens* (Pursh) Nutt.), and sagebrush. Pinyon and juniper occur on shallow, stony soils. Fire suppression and erosion has allowed this woodland to expand beyond its original range. Overall, the vegetation is not as sparse as in drier ecoregions such as Shale Deserts, Arid Canyonlands, and Sand Deserts.

Arid Canyonlands ecoregion included the inner gorge of the Colorado River and its major tributaries. Much of this ecoregion is bounded by nearly vertical, canyon walls that separate it from the adjacent, higher benchlands of the Semiarid Benchlands and Canyonlands. Soils are shallower and have a drier moisture regime than the Monticello Uplands and Semiarid Benchlands and Canyonlands. Exposed bedrock is common. Blackbrush, shadscale, and drought tolerant grasses including galleta and Indian ricegrass (*Achnatherum hymenoides* (Roemer & J.A. Schultes) Barkworth) occur. Some cropland and residential development occur near Moab.

Escarpments: Characterized by extensive, deeply dissected, cliff-bench complexes that ascend dramatically from Shale Desert or Semiarid Benchlands and Canyonlands to the forested mountain rim. Local relief can be as great as 3,000 feet. This ecoregion included major scarp slopes of the Tavaputs Plateau, the Book Cliffs, and the Grand Staircase. Natural vegetation ranges from Douglas-fir (*Pseudotsuga menziesii*) forest on steep, north facing slopes at higher elevations to desert and semidesert grassland or shrubland on lower, drier sites. Pinyon-juniper woodland often dominates escarpments and benches that are covered by shallow soils. This rugged, remote, and varied landscape provides habitat for wildlife.

Uinta Basin Floor: Lies in a large, synclinal basin that is enclosed by the Uinta Mountains and Tavaputs Plateau. Because of its topographic position, precipitation is low and soils are arid. Winters are constantly cold and often foggy due to frigid, dense air draining from the adjacent uplands and resultant air temperature inversions. This ecoregion is distinguished from other arid basins by the abundant stream runoff it receives from the mountains. Streams are often diverted for irrigation. Alfalfa, small grain and corn are grown for silage on arable, gently sloping terraces and valley floors. Stonier soils are irrigated for pasture where and when water is available. Excessive irrigation leaches salts from underlying shale, contributing salinity to the Green River and its tributaries. Non-irrigated areas are used for livestock grazing.

North Uinta Basin Slopes: A foothill area characterized by numerous mountain-fed streams that are entrenched into benches. It is warmer in winter, cooler in summer, and receives more annual precipitation than the Uinta Basin Floor. Its large number of perennial streams and extensive, stony outwash deposits set it apart from the Semiarid Benchlands and Canyonlands. Pinyon-juniper woodland is common Mountain brush occurs at higher elevations and riparian vegetation is found along stream course. Vegetation and climate contrast with the Douglas-fir forests of the neighboring ecoregion. Land use is mostly grazing and irrigated pasture but there is also some irrigated farmland. Major gas and oil fields are located within this ecoregion.

Sand Deserts is nearly level and contains a mantle of sandy eolian deposits, shifting dunes, and exposed sandstone bedrock. Entisols and Aridsols are common. The soils are sandy and have a low water holding capacity. They have a drier moisture regime than the soils of the Monticello Upland and Semiarid Benchlands and Canyonlands. On average, they receive only 5 to 18 inches of precipitation annually. Vegetation is sparser than in Semiarid Benchlands and Canyonlands and stock carrying capacity is limited. Shifting sand is mostly devoid of vegetation while soils on stable sand blanket support drought-tolerant plants including Indian ricegrass, sand dropseed (*Sporobolus* sp.), yucca (*Yucca* sp.), and blackbrush.

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APPENDIX I - FRAGMENTATION METRICS

General Category	Fragmentation Metric	Code	Ecological Information
Edge	total edge	TE	Absolute measure of edge length; needs edge density for comparison across classes; edge contrast.
Edge/Density	edge density	ED	Standardized measure of edge length; edge contrast.
Area	percentage of landscape	PLAND	Percentage of patch per class on the landscape. Landscape composition: applied to minimum area requirements.
Area	number of patches	NP	Subdivision and landscape context; may determine the number of subpopulations in a dispersed population if species is exclusively associated to that habitat type; persistence; spatial heterogeneity of landscape.
	patch density	PD	Function of total landscape area. Subdivision; number of patches per unit area; landscape structure; a larger number means greater fragmentation. Limitations include: shortest straight-line distances between focal patch and nearest same class patch.
	mean patch size	AREA_MN	A larger number may mean less fragmentation; analyze with PD.
	patch size coefficient of variation	AREA_CV	Measure of relative variation. Relative variability in size in relation to mean; measured as a percentage; larger number means more variation in size and may mean less fragmentation. Assumes normal distribution about the mean while the real distribution may be irregular.
	largest patch index	LPI	largest patch's percentage of the landscape; a small number means greater fragmentation; subdivision.
Shape Metrics	perimeter-area fractal dimension	PARFRAC	Degree of complexity of the polygon. Complex shape indicates that patch perimeter increases more rapidly as patch area increases; fractal dimension of patch shapes is suggestive of common ecological process or use influencing the patch across wide-ranging scales; computed only when $n > 10$; measures influences across various scales.

	mean shape index	SHAPE_MN	An index; a number greater than 1 means more irregular shape; a larger number may mean more irregular, "unaltered" landscapes.
Isolation	mean nearest neighbor	ENN_MN	Shortest straight-line distances between focal patch and nearest same class patch. Mean nearest neighbor; computed only if *n* > 2; a larger number may mean more isolated patches; landscape context; useful for comparison in a "remoteness model"; measure of habitat (functional) isolation. Calculates isolation only within the defined landscape where boundary is not complete barrier; roads may create a problem since they divide, but the isolation is narrow.
Contagion/ Interspersion	contagion index	CONTAG	Measures both interspersion and dispersion; as fragmentation increases, contagion decreases, subdivision increases, and functionality is impaired; a patch highly disaggregated may be more resistant or vulnerable to disturbance; a low number may mean well interspersed and small patches while a high number may mean a few large, well-clumped patches. Landscape—dispersion and interspersion of patch types; class—aggregation of patch type.
Connectivity Metrics	landscape division index	DIVISION	Probability that two animals, formerly able to move freely on the landscape, will be found in the same patch after the fragmentation takes place.
Diversity	Patch richness density	PRD	Standardizes richness to a per area basis that facilitates comparison among landscapes; a greater number may mean a higher diversity of landscapes, a more fragmented landscape.